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ECONOMIC BENEFITS OF CONTROLLING WATER POLLUTION IN AN IRRIGATED RIVER BASIN: METHODOLOGY AND APPLICATION

by

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An analytical model consisting of a water quality submodel and an economic submodel was developed. The water quality submodel consisted of three elements: parameters, water quality index functions, and an aggregation rule. The parameters defined water quality as a multidimensional vector, with each component representing some aspect of the physical, chemical, biological, and aesthetic characteristics of water affecting water uses. The water quality index functions translated the measured levels of parameters into numerical values of quality levels which water users could interpret. The aggregation rule provided a way for combining the numerical values of water quality and parameters into an overall water quality index for each use. The economic submodel viewed water as a multiple use resource, with each use having its own quality requirements. Basically, this submodel provided estimates of aggregate net social benefits to be derived from water quality changes. The model was tested and demonstrated by application to three typical water quality improvement policies: stream flow augmentation, reduced sediment levels, and reduced nitrate levels. The social benefits from flow augmentation exceeded the social benefits derived from policies reducing sediment or nitrate levels. For both stream flow augmentation and reduced nitrate levels, the annual benefits fell short of the annual costs at the highest level of water quality. These findings imply that water quality standards may be too high, and achieving these standards may not be economically efficient.

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FOREWORD

Environmental protection efforts dealing with agricultural and nonpoint sources have received increased emphasis with the passage of the Clean Water Act of 1977 (P.L. 95-217) and the subsequent implementation of the Rural Clean Water Program. As part of this Laboratory's research on the occurrence, movement, transformation, fate, impact and control of environmental contaminants, data and analytical methodologies are developed to assess the causes of and possible solutions to the environmental effects of irrigated agriculture. Economic aspects are very important considerations in dealing with the feasibility and public acceptance of environmental issues.

This study addressed the problem of measuring the economic benefits of water pollution abatement in a multiple use river setting. The primary objective of the study was to develop a multiple parameter analytical procedure for estimating benefits of water pollution abatement. Economics cannot afford to ignore water quality degradation in irrigated river basins and concentrate on water resource problems alone, as it has traditionally done. This report should benefit environmental managers as they identify and implement pollution control strategies relevant to western irrigated agriculture.

Clinton W. Hall

Clinton W. Hall, Director
Robert S. Kerr Environmental
Research Laboratory

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ABSTRACT

This study addressed the problem of measuring the economic benefits of water pollution abatement in a multiple use river setting. The primary objective of this study was to develop a multiple parameter analytical procedure for estimating benefits of water pollution abatement.

An analytical model consisting of a water quality submodel and an economic submodel was specified. The water quality submodel consisted of three elements: parameters, water quality index functions, and an aggregation rule. The parameters defined water quality as a multidimensional vector, with each component representing some aspect of the physical, chemical, biological, and aesthetic characteristics of water affecting water uses. The water quality index functions translated the measured levels of parameters into numerical values of quality levels which water users could interpret. The aggregation rule provided a way for combining the numerical values of water quality and parameters into an overall water quality index for each use.

The economic submodel viewed water as a multiple use resource, with each use having its own quality requirements. Basically, this submodel provided estimates of aggregate net social benefits to be derived from water quality changes.

The model was tested and demonstrated by application to three typical water quality improvement policies: stream flow augmentation, reduced sediment levels, and reduced nitrate levels. The social benefits from flow augmentation exceeded the social benefits derived from policies reducing sediment or nitrate levels. For both stream flow augmentation and reduced nitrate levels, the annual benefits fell short of the annual costs at the highest level of water quality. These findings imply that water quality standards may be too high, and achieving these standards may not be economically efficient.

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RELEVANT ENGLISH UNITS AND METRIC EQUIVALENTS

English Unit	Metric Equivalent	Metric Unit	English Equivalent
1 inch	2.54 cm	1 cm	0.394 inch
1 foot	0.305 meter	1 meter	3.28 feet
1 acre	0.405 hectare	1 hectare	2.471 acres
1 acre-inch	102.8 cubic meters	1 cubic meter	0.00973 acre-inch
1 bushel	35.24 liters	1 liter	0.0284 bushels
1 ton	0.9072 tonne	1 tonne	1.102 ton
1 cwt	0.454 quintals	1 quintal	2.205 cwt
1 lb	0.454 kg	1 kg	2.205 lb
1 ton/acre	2.24 tonne/ha	1 tonne/ha	0.446 ton/acre
1 lb/acre	1.12 kg/ha	1 kg/ha	0.892 lb/acre
1 cwt/acre	1.12 quintal/ha	1 quintal/ha	0.892 cwt/acre
1 gallon	3.785 liters	1 liter	0.2642 gallons

SECTION 1

INTRODUCTION

Irrigation is an age-old practice in agriculture. It was in part responsible for the rise of early civilizations along rivers. According to Burke (1978), irrigation enabled people to produce surplus food which encouraged some people to move out of farming in search of alternative employment opportunities. This led to the creation of non-farming classes such as priests, administrators, warriors, merchants, craftsmen, and artists (Eckholm, 1976).

These non-farming classes settled in small towns along rivers, forming the early civilizations in Egypt, Mesopotamia, China, Peru, Mexico, and southwestern United States[1] at various times throughout human history (Jones 1980). Later, settlements began to shift from dry irrigated areas to the more humid rainfed farming (dry agriculture) regions of the world. This shift in settlements began only during the last 1,500 years (Houston, 1977).

Today, the search for additional food and fiber is taking mankind back to the arid and semi-arid lands. These lands contain 50 percent of the earth's land surface (Houston, 1977), and a large majority of the developing countries that are plagued by food shortage lie in these arid and semi-arid lands.

Irrigation has figured heavily in the production of food and fiber for millions of people since its earliest applications. Today, it continues to be a crucial part of world food production. At the present, it is estimated that 15-20 percent of the world's cropland is irrigated, producing 30-40 percent of the world's agricultural output (Kovda, 1977; Houston, 1977). In the U.S., current irrigated cropland exceeds 20.6 million hectares[2] (51 million acres), according to the U.S. Department of Commerce (1980). The U.S. contains about 10 percent of the irrigated cropland in the world. Over 86 percent of the irrigated cropland in the

---

[1] Archaeologists have found a system of reservoirs and canals believed to be 2,000 years old in the Salt River Valley of Arizona in southwestern United States (Jones, 1980).

[2] A hectare is a metric unit of area measure and equals 2.47106 acres.

U.S. is located in the arid and semi-arid 17 western states,[3] according to the U.S. Department of Commerce (1980).

In the future, irrigation is expected to play an even more important role in the production of food and fiber for the world. Numerous irrigation projects are in the planning stages in various developing countries. According to Kovda (1977), by the year 2000, it is expected that irrigated cropland in the world will increase to 300 million hectares (741 million acres). This is about a 50 percent increase over current levels. In the U.S., there are plans to increase irrigated cropland to 22-25 million hectares (54-62 million acres) by the year 2020. Major increases in irrigated cropland are expected to be in developing countries where it is estimated that irrigated cropland will increase at about 2.9 percent per year, while nonirrigated arable cropland is expected to increase at about 0.7 percent per year (White, 1977).

Clearly, the importance of irrigation in augmenting and stabilizing food and fiber production for an ever-increasing world population needs no further elaboration. However, there is one aspect or by-product of irrigation that has not received adequate attention. This concerns its impact upon the quality of water (rivers, lakes, and aquifers) for other uses. Irrigation is usually the largest single user of diverted water in irrigated river basins. It is also usually the largest single contributor of water quality degrading sediment, pesticides, and plant nutrients (fertilizers) to receiving waters.[4]

Today, the different water uses (household, agriculture, industry, fisheries, power generation, recreation, and others) and the growing population are placing increased demands on both quantity and quality of water (Holy, 1977; Timmons, 1980). Economics should be brought to bear on the problems of degradation in irrigated river basins. It is appropriate to incorporate the water quality problem as a legitimate economic concern. This study develops a conceptual framework for estimating the economic benefits (social value) of abating water pollution in an irrigated river basin.

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[3] The 17 western states are Washington, Oregon, California, Nevada, Idaho, Utah, Arizona, Montana, Wyoming, Colorado, New Mexico, North Dakota, South Dakota, Nebraska, Kansas, Oklahoma, and Texas.

[4] This is not to suggest that all practices of irrigation contribute to water quality degradation in receiving waters. Irrigation is the general name for the various methods of artificially applying water to fields. Depending on the method of irrigation chosen, irrigation may or may not contribute pollutants to receiving water. However, in most instances, there are incentives for the irrigator to adopt irrigation methods that minimize his own cost of production and ignore external costs created in the process.

THE PROBLEM

In recent years, water pollution control has assumed importance throughout the world, particularly in the developed countries. The United Nations has designated the decade of the 1980s as the International Drinking Water Supply and Sanitation Decade. Several nations have committed themselves to better water quality in the years ahead and have adopted water quality improvement as national goals.

In the U.S., improving the quality of water receiving irrigation return flow[5] pollution is a national goal (U.S. Congress, 1972, 1977). Federal, state, and local governments are spending large sums of money to improve the water quality. According to Erskine (1972a,b) and Schultze and others (1973), there is a wide consensus in the U.S. that current levels of pollution in receiving waters should not be allowed to continue.

There are interim and final plans for improving the quality of polluted water (U.S. Congress, 1972, 1977). The interim plan[6] calls for reducing current levels of pollution in receiving streams to acceptable levels by 1983. The final plan calls for the elimination of all discharge of pollutants from any source into receiving streams by 1985. Hurt and Reinschmiedt (1979) have questioned the attainability of these water quality improvement goals without some disruption in the agricultural sector. However, the issue of the attainability or non-attainability of the water quality improvement plans is not important for the purposes of this study.

Improving the quality of water receiving irrigation return flows or any other form of pollution is not a costless endeavor. Such costs may take many forms including benefits of foregone production or other opportunities. Water quality improvement is an economic problem requiring individuals and society to make choices among economic alternatives. Not improving the quality of water receiving discharge of pollutants from various sources also has social costs in terms of foregone opportunities and associated disutilities.

Clearly, water quality management is an economic problem, as it requires individuals and society to make choices about resource allocation. To make rational choices about water quality improvements, individuals and society need information on the magnitude of benefits and costs of water quality improvements. Benefits measure the social value of water quality improvements based on individual valuation, and the costs measure the opportunity costs of the resources used for water quality improvements. Without information on benefits and costs it is impossible to say a priori whether society is providing too much or too little water quality improvements for its members.[7] Thus, the availability of benefit and cost information is the sine qua non of rational decision making in water quality management.

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[5] Irrigation return flow is a term used to refer to portions of irrigation water diverted for application to fields, but end up finding its way back to a water supply source via surface and subterranean flows. In short, it is irrigation water that would not be available for plant growth but may carry off the farm sediment, pesticides, and plant nutrients.

[6] Public Law 92-500 (U.S. Congress, 1972) actually calls for making the nation's rivers and lakes "swimmable and fishable" by 1983.

Despite the increasing effort to achieve cleaner water, information on the magnitude of benefits from water quality improvements have been scarce. Technical and empirical problems have contributed to the scarcity of benefit estimates for water quality improvements. It is not clear from the economic literature what technique one should use to quantitatively measure water quality. Also, the lack of markets for water quality presents conceptual problems in determining the value of water quality improvements.

In traditional economic analysis, one usually deals with homogeneous goods, and the question of quality never arises. Traditional economic analysis does not distinguish between slight quality variations in a specific good (e.g., water) and an entirely different good (e.g., bread). Quantification problems are confounded by the fact that water quality also has attributes of a public good. Quality improvements are equally available to everyone in the vicinity. Hence, they cannot be exclusively provided to people who are prepared to pay for them wthout incurring high costs to exclude non-payers. It may be that the costs required to exclude those who are not willing to pay for the services may at times exceed the revenues generated by exclusion.

Despite the lack of quantitative measure for water quality and market prices for its value, society still demands cleaner water supply sources. Clearly, there is a genuine need for the development of a conceptual framework that (1) provides a scheme for quantifying water quality and (2) does not rely on the availability of market prices for water quality in order to be able to estimate the benefits (social value) that society attaches to cleaner water. This study is an attempt to develop such an approach.

CONCEPTUAL FRAMEWORK

Ayres and Kneese (1969) conceptualize environmental pollution and its management as a materials balance problem. The economy extracts productive resources from the natural environment. In the short run, these productive resources are partly converted into final goods and partly become waste residuals. In the long run, final goods also ultimately become waste residuals. Thus, in a closed economy (no exports and no imports), the long-term amount of waste residuals discharged into the natural environment must be equal to the mass of productive resources extracted from the natural environment.

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[7] Society is said to provide the right level of water quality when the benefits obtained from the last unit of pollution control equals the marginal cost of pollution control.

The materials balance view is based on the law of conservation of mass. This law says that materials may change in form[8] (e.g., from solid to liquid), but their mass remains constant.[9] The materials balance approach is very useful in gaining a broader understanding of environmental pollution problems. It provides an accounting system which traces the flow of productive resources from the natural environment as waste residuals at a given time. Thus, the natural environment is the ultimate supplier of productive resources and receiver of water residuals. The economy holds productive resources and residuals only temporarily. Figure 1 adopted from Maler (1974) depicts the flow of materials (productive resources and waste residuals) between the natural environment and the economy. Arrows show the direction of material flow.

Kneese and Bower (1972, 1979), Freeman (1972), Maler (1974), and Kneese and Schultze (1975) view the natural environment as a common property asset yielding productive resources to producers and a flow of environmental services to consumers. A common property resource is a natural asset that cannot, or can only imperfectly, be reduced to private ownership (Kneese and Bower, 1979). Some examples of common property resources are water courses, air mantle, landscapes, and ecological systems.

A river flowing through an irrigated river basin is a common property resource. It provides the farmer with irrigation water for crop production. It also provides a flow of other services to the residents of the basin, for example, fishing and recreational opportunities. The river can meet these demands as long as its waste assimilative capacity[10] is not exceeded. The waste assimilative capacity of a river is affected among other things by the quantity of water in the watercourse, velocity of water, and nature of residuals inserted. In general, the greater the quantity of water in the watercourse and the faster the velocity of the water, the higher is the assimilative capacity of a river, provided the residuals are easily

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[8] Perhaps state is a preferred word as it refers to the three states of matter (solid, liquid, and gas).

[9] Note that the concentration of a material (e.g., nitrogen, phosphorus, etc.) can vary at a given location as a result of human and natural activities. But the total mass of a material distributed in all the locations is constant.

[10] The waste assimilative capacity of a river refers to the ability of the river to break down residual wastes inserted into it into harmless natural substances. In short, it refers to the ability of the stream to cleanse itself of residual wastes.

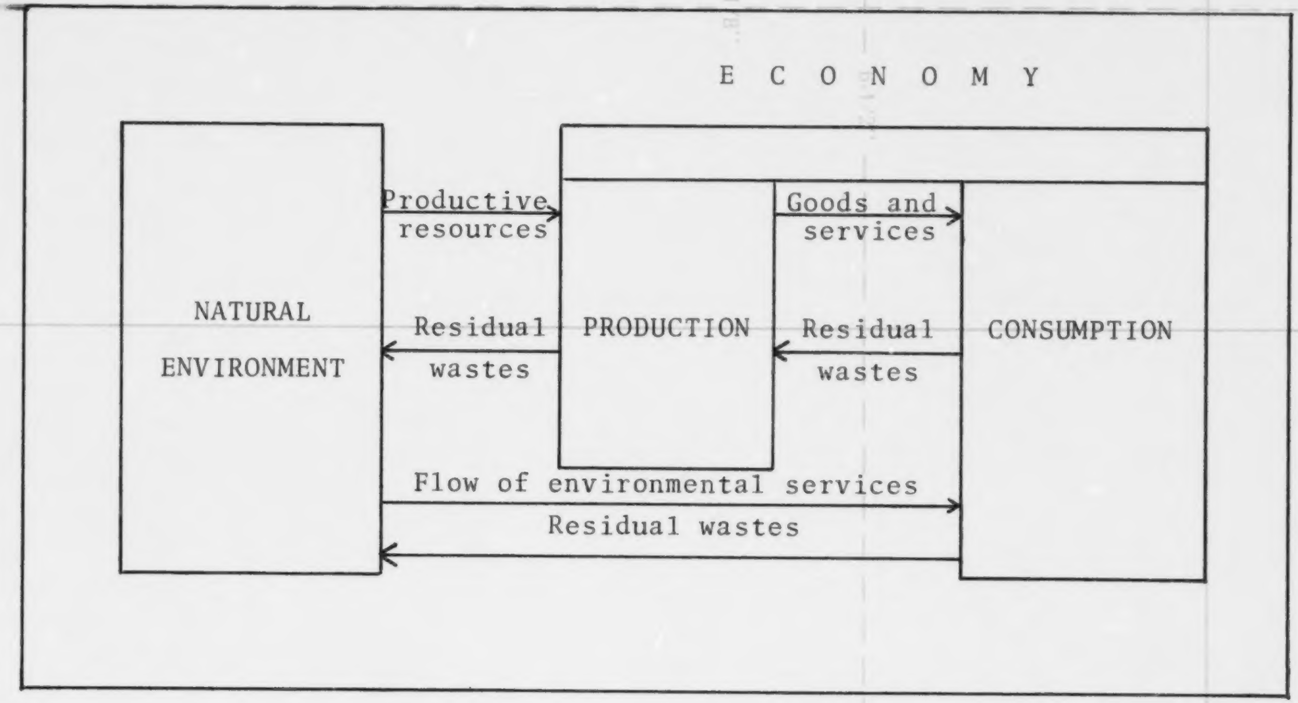
E C O N O M Y
NATURAL ENVIRONMENT
PRODUCTION
CONSUMPTION
Productive resources
Residual wastes
Goods and services
Residual wastes
Flow of environmental services
Residual wastes

Figure 1. Flow of materials between the natural environment and the economy.

soluble in water. Some residuals, for example many pesticides,[11] are not easily soluble in water (National Academy of Sciences, 1973).

The water quality of a river is affected by the flow of residual wastes from the processes of production and consumption. In irrigated river basins, agricultural economic activities, particularly irrigation, contribute sediment, pesticides, phosphorus, and nitrogen residuals to rivers. Sediments render rivers less useful for recreational uses. Phosphorus and nitrogen accelerate the growth of objectionable aquatic plants. Aquatic plants compete with fish and other organisms for dissolved oxygen while also reducing the recreational value of the water. Thus, the legitimate application of irrigation water to increase crop production on the farm creates unintended external effects on downstream farmers, recreationists, and fishermen. The effect is external to the irrigator because the present institutional arrangement does not require him to take into consideration the external effects that he creates.[12]

One way of forcing the irrigator to take account of the pollution he creates is by pricing the external effects. Under conventional rules, the price of river water pollution to the irrigator is zero; but to the other water users, the value of the unintended external effects (pollution) are the foregone opportunities. The value may not be zero to other irrigators located downstream.

Some water uses such as irrigation, power generation, and household uses are private. The users of these services incur charges.[13] On the other hand, recreational and fishing uses are public. One may enjoy the use of these services for a zero or near zero charge. Thus, one may visualize the flow of services from a river as being both private and public goods.[14] Since these are generally competitive, one cannot increase the flow of private services without reducing the flow of public services.

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[11] Pesticides are natural and synthetic chemicals used to control or destroy plant and animal life considered to be adverse to individuals and society (National Academy of Sciences, 1973).

[12] The price system gives the wrong signal to the irrigator; that is, it incorrectly tells irrigators that these unintended external effects have no prices. Consequently, farmers do not take these external effects into consideration in making their decisions.

[13] These users do not pay the full costs of the services in all cases, but could still be excluded from the services if user costs are not paid.

[14] Hall (1972) has indicated that Hite had suggested dividing the services of the environment into private goods and public goods.

Bradford (1970) developed a theoretical framework that allows the derivation of a "bid curve" for a public good in terms of a private good based on ordinary indifference curve analysis. A "bid curve" is a function describing the maximum amount of the private good than an individual is willing to give up (pay) to obtain a small change in the public good, while maintaining a constant level of utility.[15] Aggregation of individual bid curves gives the aggregate bid curve for the public good in terms of the private good. Hence, by proper choice of the units of the private good (for example, money), one can derive monetary values for the public good.

This study used the framework proposed by Bradford as a starting point in the development of an analytical procedure that provides tow measures of benefits (willingness to pay and minimum required compensation measures) of water quality changes in a multiple use river basin setting.

OBJECTIVES OF THE STUDY

This study addresses itself to both the conceptual and empirical problems of measuring water pollution abatement and benefits in a multiple use river setting. Three major objectives direct this analysis.

The first objective is to review the literature for relevant economic theory, methodology, and research effort to aid in developing a conceptual framework for measuring water pollution abatement benefits. The second objective is to develop a generalized methodology for estimating the benefits of water pollution abatement. The third objective of this study is to empirically apply the methodology developed for estimating the benefits of water pollution abatement to a case study in the Yakima River Basin of south central Washington state.

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[15] Note that ordinary demand analysis derives the demand function for an economic good holding income constant while a compensated demand analysis derives the demand for a good while holding individuals on their respective indifference curves (constant utility).

SECTION 2

CONCLUSIONS

This study estimated the aggregate economic benefits from raising the level of water quality to near a level of perfection in the Yakima River of Central Washington. The user benefits included those for fishing, recreation, and agriculture. In the setting of this river basin, benefits of about $2.5 million annually were derived, based upon the willingness to pay measure. In addition, the benefits from specific policies to reduce nitrate levels, reduce sediment levels, and increase stream flow were also estimated. The aggregate benefits from these policies would be less than those from the general policy to raise water quality to a level of perfection.

Previous studies have shown that the costs for implementing the latter three specific policies could range from $12 to $20 million annually. Therefore, there is reason to question the implementation of these specific policies. At least, if judged on the criterion of economic efficiency it may be prudent to stop short of the quality level suggested for those policies.

The finding that estimated social benefits from water pollution abatement may fall far short of incurred costs in some cases suggests that stated water quality standards may be too high for those circumstances. However, the procedure developed and demonstrated in this study would help to determine the level of water quality at which social benefits and costs of pollution abatement are in proper balance. If such a procedure were employed, the role of economic efficiency could become much larger in environmental planning. In any case, it is implied that water quality standards be set according to the benefits that are to be derived. Site specific analyses would be required to carry out such a policy of environmental management. However, the potential efficiency and public acceptance of such policies could be greatly improved.

SECTION 3

REVIEW OF THE LITERATURE

The purpose of this section is to selectively review relevant empirical benefit studies on water quality improvements. This review of the literature is intended to provide some background and direction for the research effort at hand and other similar future efforts. This review is organized as follows. First, a short history of the theoretical and empirical developments of the general concept of benefit is given. Economists and others who developed and applied the concept of benefit are recognized.

The criteria chosen for evaluating the empirical benefit studies to be reviewed are then discussed. The third major section is a review of the empirical benefit literature. The empirical benefit studies on water quality improvements are divided into instream water uses and diversion (withdrawal) uses for ease of exposition and manageability only. Non-user benefits such as option demand, bequest demand, and existence demand are discussed in a separate section. Finally, a summary and an assessment of the benefit literature concludes the chapter.

HISTORY OF BENEFIT MEASUREMENT

Theoretical Development

Dupuit (1844) was the first to propose measuring social (public) benefits. In a classic discussion on the measurement of the utility of public works like roads, canals, railways, and bridges, Dupuit pointed out the weakness of equating the value (benefit) of such a good with the price paid for it. He argued that many users of the good, if necessary, would pay more than the actual price rather than do without the good. Dupuit also pointed out that the consumer never pays more for a good than the value he places on the utility derived from using the good. If the utility derived from using the good is less than its best alternative, then the consumer would not willingly purchase that good since price exceeds value. A consumer would thus purchase a good only if its value is greater than or equal to its price. Dupuit (1844, p. 262) defined the value (benefit) of a good to be "the maximum sacrifice which each consumer would be willing to make in order to acquire the object."

Dupuit also introduced the concept of consumer's surplus in that classic discussion on the utility of public works. He claimed that consumers may receive unearned surpluses when they engage in market exchange. Dupuit (1844,

p. 262-263) defined consumer's surplus as "the difference between the sacrifice which the purchaser would be willing to make in order to get it, and the purchase price he has to pay in exchange." He suggested that consumer's surplus can be measured as the area to the left of the market demand curve[1] and above the market price line. Dupuit, however, did not underscore the theoretical foundations of the concept of consumer's surplus and did not anticipate any problems with measuring it. Marshall (1920) and Hicks (1941, 1956) recognized the controversy that could arise in the measurement of consumer's surplus and determined appropriate restrictions for its application. Marshall originated the constant marginal utility of money assumption. This assumption makes the area under the market demand curve above the price line an unambiguous measure of social surplus value.

The rejection of cardinalism and interpersonal comparability of utility resulting from the works of Robbins (1938, 1948) and others cast more doubt on the usefulness of consumer's surplus as a measure of social value. Hicks (1941) rehabilitated the concept of consumer's surplus using ordinal indifference curves. He defined consumer's surplus as the amount the consumer would pay or need to be paid to be just as well off after the change (price or quantity change) as he was before the change. In addition, Hicks also introduced four different measures of consumer's welfare change resulting from an actual or proposed price change. These four measures of consumer's welfare change are compensating variation, compensating surplus, equivalent variation, and equivalent surplus. Hicks pointed out that the four welfare change measures would be equal to each other and equal to the area under the market demand curve above the price line if the income effect is zero.

Hicks indicated that consumer's surplus is an analytical tool of great power, whose use is perfectly legitimate in measuring consumer welfare change if proper precautions are taken. Samuelson (1947) and Little (1950) disagreed with Hicks, claiming that the concept of consumer's surplus is of little use in welfare economics. Despite the controversy among economic theorists, consumer's surplus is a widely used concept in applied welfare economics (Hausman, 1981). The remaining portion of this section deals briefly with the efforts of various agencies in implementing the concept of benefits as visualized by Dupuit and further developed by others.

Empirical Development

Essentially, the history of benefit estimation is the history of efforts to apply the idea put forward by Dupuit. It would not be practical to try to document all such efforts. Instead, emphasis will be put on major publications and guidelines issued by government agencies and others for the valuation of the benefits of public projects. The reader should be warned that this review of benefit estimation to be presented is selective and reports primarily on the American experience. As a result, important contributions from outside the United States and in languages other than English have been overlooked.

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[1] Dupuit (1844, p. 280) referred to the demand curve as a "curve of consumption." Interestingly, in all his figures, he put price on the horizontal axis and quantity on the vertical axis.

The River and Harbor Act of 1902 was one of the earlier documents that required the Army Corps of Engineers to report on commerce benefits due to improved navigation. The Act made the distinction between national benefits and local benefits and required a report of the local benefits as a means for determining the cost that should be allocated to local interest. The Act required that benefits be estimated, but did not say how. It also left the responsibility for determining the benefits with a board of engineers.

The Flood Control Act of 1936 (U.S. Congress, 1936) was instrumental in expanding the use of economic criterion in public decision-making. The Flood Control Act required that "if the benefits to whomsoever they may accrue are in excess of the estimated costs," it is the responsibility of the federal government to control floods on all navigable U.S. rivers. After the passage of the Flood Control Act of 1936, the scope of benefit estimation expanded and other federal agencies that were responsible for water and land resources development began making estimates of benefits and costs. The federal agencies responsible for water resources development (U.S. Army Corps of Engineers, U.S. Bureau of Reclamation, and Tennessee Valley Authority) widened the scope of benefit estimation by including secondary and intangible project benefits in addition to the primary benefits. The addition of secondary and intangible benefits to primary project benefits tends to give a higher total benefit for a project, making it more desirable. Because the different federal agencies competed with each other for federal funds, by the mid-1940s it was felt that the various federal agencies must use a consistent procedure for estimating project benefits. As a result, a Federal Inter-Agency River Basin Committee was set up in 1946 to formulate mutually acceptable principles and procedures for estimating benefits and costs of water resources development.

The Federal Inter-Agency River Basin Committee (1950) developed the "Green Book." The "Green Book" set forth a complete set of principles for project evaluation and introduced the terms and the concepts of welfare economics into project evaluation. According to Eckstein (1958), the "Green Book" made many specific recommendations on estimating benefits and costs of projects which were opposed to agency practices. However, as a guideline for project evaluation it left ambiguities that permitted certain practices which were contrary to its general point of view. Because of these ambiguities, the "Green Book" as a guideline for project evaluation showed weaknesses that needed correcting.

Prior to the revision of the "Green Book" by the Federal Inter-Agency River Basin Committee (1950), the Estimates Division of the Bureau of the Budget (1952) prepared what was called Circular A-47 to promote greater uniformity of evaluation standards among federal agencies. The circular contained a summary of the basic policies of water resources programs which would guide the Bureau of the Budget in its evaluation of projects. Circular A-47 also required federal agencies to submit certain data on a uniform basis to allow comparison within the entire water resources development program. A major problem with the original "Green Book" and its revision was the emphasis on economic efficiency goals, while neglecting other goals.

In 1962, the President's Water Resource Council (1962) produced Senate Document 97 to serve as a guide in the evaluation of benefits and costs of water and related land resources development. Senate Document 97 was firmly grounded in economic theory; however, it also called for consideration of project contributions to social well-being and preservation objectives.

The next major change in water resource project evaluations was in 1973 when the Water Resources Council (1973) established the multiple objectives of national economic development, regional economic development, social well-being, and environmental quality. It also proposed three alternative techniques that can be used to calculate an estimate of the total benefits of a project. These are willingness to pay, change in net income, and most likely alternatives. It specified under what set of conditions each of these three techniques are appropriate for obtaining estimate of benefits.

The guidelines for benefit estimation went through many revisions to overcome various weaknesses and compromise between competing interest groups. Even though they purported to incorporate the rigorous methods of economic analysis, some of the procedures were not conceptually correct. Revisions were needed to gradually weed out these procedures. Economists commented and often recommended that the guidelines be consistent with the methods of economic analysis.

One thing is clear from this brief discussion. Application of the concept of benefits has come a long way. Given the current state-of-the-art of benefit estimation in the area of environmental development, however, the theoretically correct measure of benefits still is to be developed.

CRITERIA FOR EVALUATION OF BENEFIT STUDIES

Empirical water quality studies are undertaken to provide information on the social worth of alternative water quality improvement programs. In so doing, it is essential that benefit estimates be based on theoretically correct procedures.

Three criteria are selected to evaluate the following empirical benefit studies. First, the method used for estimating benefits should be based on economic theory. That is, it must be theoretically sound. This requirement is important because it is not sufficient to provide value estimates without an economic explanation for the value obtained. Second, the method to be used should be capable of quantifying and monetizing benefits. To be useful to decision-makers, values must be attached to the services of water quality improvements. Third, the method chosen for estimating benefits of water quality improvements should incorporate water quality variables in the analysis. This is essential because one needs to link water quality, water, use and the values attached to different quality levels. For additional criteria the interested reader should refer to Freeman (1979) and Meta Systems (1979).

First, literature dealing with instream water uses is reviewed. Instream water uses include swimming, boating, fishing, water skiing, rafting, canoeing, picnicking, sightseeing, wildlife enhancement, power generation, navigation, and others. Second, studies dealing with benefits of water quality improvements in diversion or out-of-stream uses are observed. Diversion uses include water supply, industrial and agricultural uses.

For each study reviewed, the emphasis will be on the approach used to derive benefit estimates of water quality improvements for a particular water use. The method used is emphasized for two reasons. First, underlying the method used to derive benefit estimates is a theoretical model and an analytical procedure. Second, emphasizing the method used enables one to accumulate an inventory of methods for estimating benefits of water quality improvements. This is helpful in developing an approach that can be used for estimating benefits of abating pollution. For each type of water use only one study will be reviewed unless there are different methods for estimating benefits for that particular use. To facilitate communication, instream water uses will be referred to as recreational uses.

RECREATIONAL WATER USES

Rivers that are used in the creation of water recreational activities are providing extra-market goods. No market prices exist for the services of these resources. However, the lack of markets and market prices does not mean that these resources are not useful to man.

In the absence of market prices for the quality of recreational resources, several approaches have been developed to estimate their value.

The Willingness to Pay Method

This approach was developed by Davis (1963). It utilizes a questionnaire or an interview technique and directly asks individuals to reveal their willingness to pay for improving the quality of a resource.

Gramlich (1975, 1977) analyzed the demand for river water quality in the Charles River, Massachusetts. The study consisted of a survey of 165 families in the Boston Metropolitan Area. The questionnaire requested information on (1) annual willingness to pay for a guaranteed improvment to swimmable water quality throughout the Charles River; (2) annual willingness to pay for a guarantee of swimmable water quality throughout all the nation's rivers; and (3) the respondent's socio-economic characteristics such as income, age, education, distance from river, etc.

The results of the survey showed that the average aggregate annual willingness to pay for a guaranteed improvement to swimmable water quality throughout the Charles River was $30.54 per household. Gramlich analyzed the survey results using multiple regression analysis. He found that income significantly affected willingness to pay for water quality improvements. His analysis also showed that the income elasticity of demand for clean river water was less than one; i.e., a 1 percent increase in income gives rise to a less than 1 percent increase in willingness to pay for water quality improvements. His study found that the level of education of people was positively related with the value placed on water quality. The study also found that families residing close to the Charles River were willing to pay substantially more than families residing far away.

Gramlich's study is based on sound economic theory. He also provides a monetary estimate of the benefits of improving the quality of the Charles River. This study did not directly incorporate water quality parameters in the analysis. It did, however, classify water quality into levels A, B, C, D, and E and define each quality level in general terms. It did not, however, isolate the parameters that are responsible for water quality deterioration in the Charles River, although Gramlich recognized the need to incorporate measures of water quality in any quality improvement study. The author was aware of the limitations of the direct method in obtaining truthful responses.

Oster (1977) reported the results of a study that estimated the benefits of water pollution abatement in the Merrimack River Basin, New Hampshire. The study consisted of a telephone survey of 200 residents of 50 towns along the Merrimack River during the winter of 1973-1974. The survey provided socio-economic information (such as income, education, sex, family size, and home ownership) about the respondents. In addition, the survey obtained information on a respondent's annual willingness to pay either in the form of a tax or direct payment to water quality improvement. The survey also obtained information on the respondent's expected annual use of the river (for boating, swimming, and fishing) after it had been cleaned up.

Oster analyzed the survey results by cross-tabulations of income with willingness to pay and frequency of use. She found that both willingness to pay for water quality improvement and water use increase with income, suggesting that water quality is a normal good. In particular, Oster found that the average annual willingness per respondent to pay for river quality improvements in the Merrimack River Basin was slightly over $12 and the median number of days that respondents expected to use the river, given a cleanup effort, was 13 days per year.

Oster's study derived a monetary measure of the benefits of water quality improvements in the Merrimack River. The study failed, however, to incorporate water quality parameters into the analysis, and it is not clear from the study to what level the river was to be improved. The choice facing society is not between a polluted or clean stream. The author points out that the Merrimack River is the third most polluted river in the nation trailing only Cayahoga in Ohio and the Houston ship canal in Texas. However, the study does not provide information on the level of pollutants that are causing the water quality problem except that pollutants are discharged from industries and municipalities. Another problem with the study is that it yields no information about the optimal level of river water quality. The study determined only willingness to pay to improve water quality from the status quo quality level (polluted) to a clean quality level. However, to determine optimal level of water quality improvements one needs information on marginal benefits and marginal costs associated with different water quality levels.

Davidson, Adams, and Seneca (1966) reported on a study that attempted to estimate the value of water quality improvements in the Delaware estuary. This study used data from a 1959 survey conducted by the University of Michigan Survey Research Center of 1352 households. The survey requested socio-economic data from each household interviewed on the household's frequency of participation in water recreational activities (swimming, boating, and fishing). The survey, however, did not provide information on each household's willingness to pay for improving the quality of recreational facilities.

Davidson et al. (1966) selected dissolved oxygen as a proxy variable for water quality in the river. they used regression analysis to isolate the exogeneous variables that influence participation in boating, swimming, and fishing. Socio-economic variables (income, age, sex, education, race, and occupation) and locational factors were found to be important in determining a household's participation in water recreational activities.

In estimating the benefits of water quality improvement, the authors determined the present value of the total days of all water recreational activities. It was assumed that the only beneficiaries of water quality improvement in the Delaware Estuary are consumers of water recreational activities.

Davidson, et al. used expert ratings of the fishing facility of the Delaware Estuary with improved water quality, that is, with increased levels of dissolved oxygen. The total days of participation in each water recreational activity was determined by the number of participants in each activity and the mean number of days of participation per individual. Taking into account changes in population, income, and education, the authors made projections of total activity days for the years 1975 and 1990. The total days of participation in each recreational activity were then discounted back to 1965 using a 5 percent discount rate for two scenarios, with and without water quality improvement. The difference between the present values for each recreational activity with and without water quality improvement was defined as the measure of the social benefits of water quality improvement for the participants of the water recreational activity. For example, they estimated the benefits of water quality improvements, for boating and fishing uses, to be 8,766,100 activity days and 880,724 activity days, respectively. Assuming a given arbitrary dollar value for a day of participation in a given water recreational activity, the authors feel that one may convert the marginal activity days schedule into a family of benefit curves. The marginal cost estimates for improving the water quality in the Delaware Estuary were obtained from the Public Health Services' Delaware Estuary Comprehensive Study. This study gave cost estimates for varying water quality conditions in the Delaware River from 2 mg/liter to 4 mg/liter of dissolved oxygen.

The study of Davidson et al. (1966) does not provide an actual monetary measure of the value of water quality improvements in the Delaware Estuary. It provides estimates of additional number of days of recreation that will ensue with water quality improvements.

The dissolved oxygen variable, however, does not enter into the analysis. In fact, the authors used an expert rating of the recreational facilities in their regression equations. The dissolved oxygen variable was introduced in the last part of the analysis where the estimates of marginal costs of water quality improvement are given. In addition, since the level of dissolved oxygen is only one factor determining water quality in the estuary even for recreational use, concentrating on one variable may have provided an inadequate measure of water quality. Overall, the study is based on sound economic theory; however, it did not provide a monetary measure of the value of improved water quality.

Among other studies that used the direct questioning approach of the user population to derive willingness to pay for use of a recreational resource are Davis (1963) and Hammack and Brown (1974). For other references see Dwyer, Kelly, and Bowes (1977).

The Travel Cost Method

According to Prewitt (1949) this approach was conceived by Hotelling. Hotelling suggested that areas surrounding recreational sites be divided into concentric zones and average travel costs to the recreational site from each zone be computed. The travel cost was to be used as a proxy for price. Clawson (1959) was among the first to apply the travel cost method for the purposes of estimating benefits of recreational resources. The travel cost method has undergone some refinements since it was used by Clawson. Contributors to the improvement of the travel cost method are many. Laub (1974) and Dwyer et al. (1977) provide an extensive list of contributors. Here, only the basic travel cost model will be discussed based on Laub (1974) to give the reader an overview of the approach.

The basic travel cost model defines concentric zones around the recreational site and groups recreationists to the geographic zone they live in. Both travel costs of the average recreationist from each zone and number of visits per thousand of population per year from each zone to the recreation area are computed. Figure 2 adapted from Laub (1974) and Scott (1965), graphically presents the relationships between travel cost and annual number of visits per thousand population for a hypothetical recreational resource. Assume the recreationists that use the resource have been grouped into five zones based on their distance from the recreational area. Note that OA, OB, OC, OD, and OE are the travel costs to the recreational area and OF, OG, OH, OI, and O are the number of visits per thousand population from zones 1, 2, 3, 4, and 5, respectively.

Assume user fees amounting to AB are charged to residents of zone one. This increases the travel cost to the average recreationist from zone one from OA to OB. This increase in travel cost to residents of zone one

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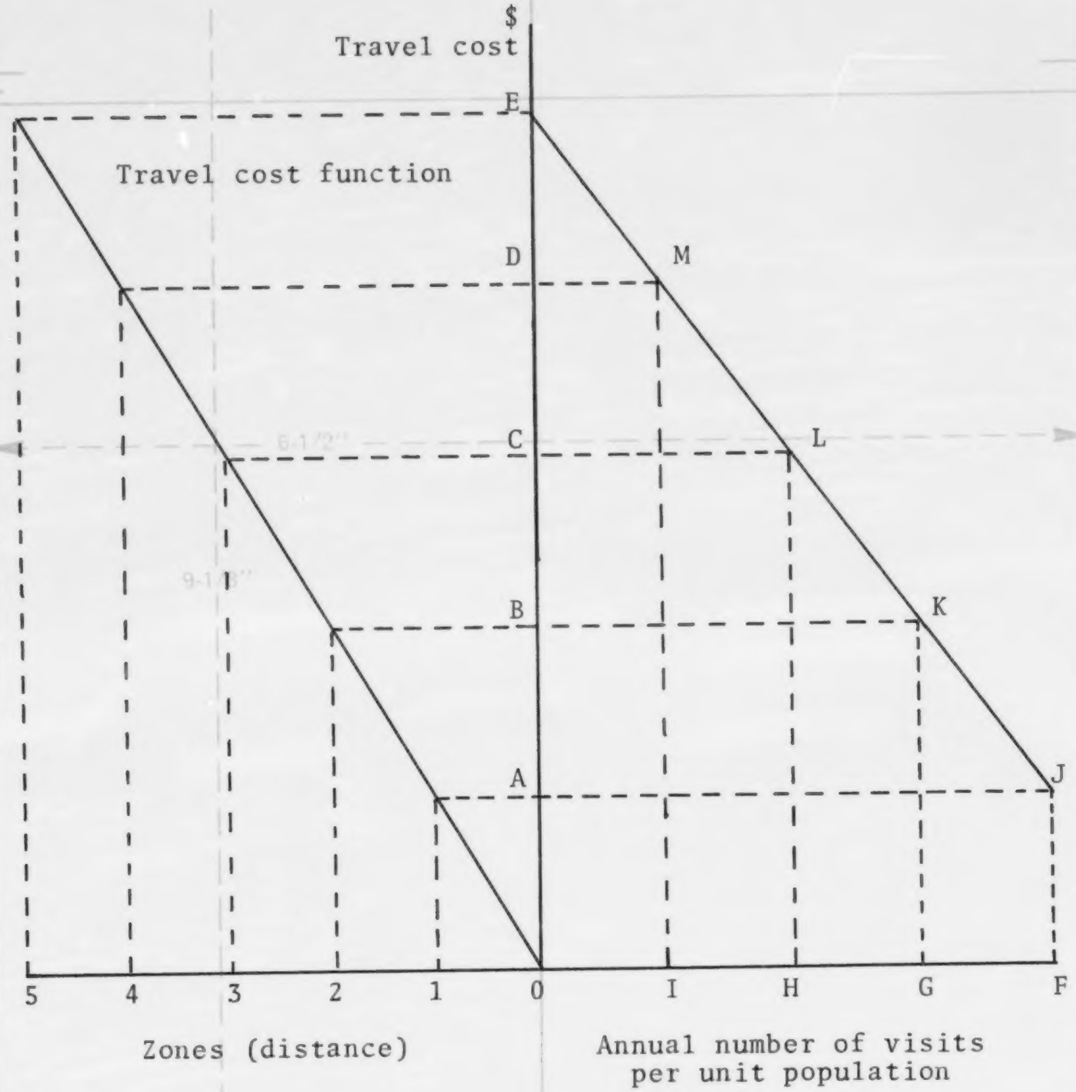

Figure 2. Relationship between travel cost and annual number of visits to a hypothetical recreational site.

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reduces the annual number of vists from OF to OG. Similarly, if the travel cost to residents of zone one is increased to OC the number of visits drops to OH. Finally, if the travel cost is OE to residents of zone one, there would not be any visits. Clearly, EJ can be viewed as a demand curve of residents of zone one. Similarly EK, EL, and EM become the demand curves of the residents of zones 2, 3, and 4, respectively, as the travel costs from each zone are varied. The aggregate demand curve for the resource is obtained by summing the demand curves of the residents of each zone horizontally. Before summing the demand curves, one needs to convert the annual number of visits to normal quantity by multiplying it by population of each zone. The area under the aggregate demand curve gives the total benefits that recreationsit derive from the recreational facility.

In empirical applications of the travel cost method, regression analysis is used to estimate an equation that predicts number of visits per unit of population for each zone. The equation that predicts the number of visits is obtained from observations on number of visits by residents of the various zones and socio-economic variables such as income, population, family size, etc. The function relating number of visits to distance and socio-economic variables is used to predict the number of visits forthcoming from each zone for various hypothetical changes in travel costs. Aggregating the number of visits over all zones for each travel cost increment gives the demand curve for the recreational resource.

Despite its popularity in the recreation literature, the travel cost method has weaknesses. According to Laub (1974), the major weakness is that the approach implicitly assumes the same functional relationships exist between the number of visits and all other variables for all zones. In addition, all of the demand curves for various zones are derived from a single visitation rate prediction model. To use such a model, however, one needs to assume that (1) residents of all zones have similar preferences; (2) residents of all zones face similar alternatives; (3) residents of all zones consume the same recreational commodity; and (4) all recreationists make single purpose trips, i.e., to visit only the recreational site. The validity of these assumptions is questionable. The interested reader should refer to Laub (1974) and Dwyer et al. (1977) for more discussion of this method.

Reiling, Gibbs, and Stoevener (1973) reported on a study that estimated the economic benefits accruing to society from water quality improvements of a recreational facility--Lake Klamath, Oregon. The study consisted of developing a statistical demand model to estimate the benefits of water quality improvements in Lake Klamath. The demand model focused upon individual recreationists and separated the traditional price variables (average cost) into on-site costs and travel costs. The demand model was used to estimate the number of days the recreationist would stay at Klamath Lake as the water quality was improved.

A field survey of 300 recreationists at four lakes (Klamath Lake, Lake of the Woods, Odell, and Willow) provided information on the characteristics of the users that were used to estimate equations of the statistical demand model. Data collected at Lake of the Woods, Odell, and Willow were used to derive a relationship between the number of visits to a site and the characteristics of the site. The specific site characteristics considered by the study were the areas of the lakes and the level of use of each lake for various recreational activities (swimming, water skiing, boating, fishing, camping, and picnicking). Discrete values were used to indicate how intensively each of the lakes was used for each activity. Low, medium, and high uses of the lake for a given activity were assigned values of one, two, and three, respectively.

The estimated relationship between the number of visits to a site and the characteristics of the site was then used to estimate the increase in the number of visits to Lake Klamath as the water quality would be improved. Reiling et al. (1973) estimated the impact of increased recreational use of the Klamath Lake because of water quality improvement on the local economy by employing an input-output model of the Klamath County economy.

Reiling et al. (1973) developed an elaborate procedure for estimating the benefits of improved lake water quality. The study was theoretically sound and provided a monetary measure of the benefits of water quality improvements. The study did not incorporate conventional water quality variables in the analysis. The areas of the lakes and use intensities were used as proxy for water quality. In a real sense, however, they did not measure water quality. The study used expert opinions to assign use intensities to each lake for every activity. In addition, an implicit assumption that the four lakes are alike in all aspects was made.

Overall, the Reiling et al. study provides some new insights particularly into the evaluation of secondary benefits by using input-output models depicting the local economy. However, it does not define water quality in the conventional sense using water quality parameters. Neither does it provide values that recreationists attach to changes in these variables.

Another study that used the travel cost method to estimate the benefits of pollution control was by Stevens (1966). Stevens estimated benefits that accrue to sport anglers from improvement of the water quality of Yaquina Bay, Oregon. The study consisted of specifying and estimating demand equations for three types of sport fisheries. The water quality variable in the demand equations was angling success per unit of effort (the marginal product of the biological production where fish catch or yield is the output and angling effort measured in time is the input). Data on the characteristics of the anglers were obtained through direct interview and mail questionnaires. Multiple regression analysis was used to isolate the determinants of demand for each sporting fishery.

Stevens utilized conventional demand theory as a framework for his analysis. He also provided monetary estimates of the benefits of pollution control in the Yaquina Bay. It appears, however, there would be some problems with the choice of angling success per unit effort as a water quality variable. Angling success may be influenced by factors other than water quality. Although angling success may not be a reliable indicator of water quality, it still may be the best measure of water quality improvement if fishing is the only use to be valued.

Recently, the travel cost method has undergone some methodological refinements. Contributors to the methodological improvement include Burt and Brewer (1971) and Cesario and Knetsch (1970). These methodological developments have enabled the travel cost method to take explicit account of substitute recreational facilities in estimating the demand for a recreational site. The earlier travel cost models estimated only the demand for a recreational site, thus overestimating the benefits of the site by ignoring the substitute recreational facilities that are available.

The Gross Expenditure Method

This approach values recreational benefits as being equivalent to the total cost that the recreationists incur to enjoy the services of recreational facilities. The total expenditure consists of travel expenses, equipment cost, and expenses incurred while in the recreation area. It is argued that persons incurring such expenditures must have received commensurate value or they would have not incurred the expenses.

Economists in general agree that estimating the benefits of a recreational facility by the gross expenditure method is theoretically incorrect (Crutchfield, 1972; Stevens, 1966; Knetsch and Davis, 1966). What is needed is the net increase in value above what would occur in the absence of a particular recreational opportunity. But what is obtained is a gross value which perhaps gives an indication of the significance of the recreational facility on the economy of the area. Since the gross expenditure method does not measure the social worth or benefit of the recreational facility, studies that used the gross expenditure approach to estimate benefits of pollution control will not be reviewed. However, for the interested reader, it should be noted that a number of studies have used the gross expenditure approach in estimating recreational benefits, including Faro and Nemerow (1969) and Mahoney (1960).

The Cost Method

The cost method of estimating benefits is predicated on the assumption that the value or benefit of a recreational facility is equal to or greater than the cost of making the facility available. This approach has one serious problem. It justifies every project since it assumes that cost estimates provide a lower bound for the benefit estimate. This method does not help in choosing among alternative projects since for all projects benefits outweigh costs (Knetsch and Davis, 1966). The problem with this approach is that it emphasizes only the cost of making the facility available while ignoring the demand for the services of the facility, hoping that supply will create its own demand.

The Revenue Method

The most widely used approach in estimating the impact of water quality improvements on commercial fishermen is the revenue method. This method estimates benefits foregone as being equal to the revenue lost due to deterioration in water quality. In a similar fashion, improvements in water quality increase the fishermen's revenues (incomes) by increasing fish production and the probability of catching fish. However, water quality improvements on a large scale may increase the aggregate supply of fish and may depress prices received by fishermen or merely attract more fishermen.

The Council on Environmental Quality (1971) used the revenue method in estimating the national revenue loss of marine commercial shellfishing due to water pollution. The study by the Council on Environmental Quality (1971) shows methodological deficiencies. First, the price per unit of fish was arbitrarily assigned or assumed and not based on social valuation. Second, the study left out consumer's surplus in computing the social loss due to water pollution.

The Hedonic Price Technique

The hedonic price technique was an approach developed by Griliches (1971) and others for estimating the value of product quality variation for consumer goods. The hedonic price technique imputes values to the characteristics which differentiate already related products in a product class. For example, automobiles constitute a product class differentiated by the number of doors and gas mileage. Given a sufficient number of car models with different combinations of doors and gas mileage, it is possible to estimate an implicit price function which gives the market price of any automobile as a function of the quantities of its various characteristics.

The concept of the hedonic price technique has been applied to the valuation of environmental quality change. Some examples are Freeman (1974) and Anderson and Crocker (1972). Most studies that applied the hedonic price technique to estimate the benefits of environmental quality change are in the area of air pollution. One of the hindrances to the use of the hedonic price technique in water quality studies is that market prices do not exist for overall water quality. Another problem is that water quality parameters in a given river or lake tend to vary slightly. On the other hand, air pollution data varies considerably even within a given city and is amenable for analysis with the hedonic price technique which normally employs multiple regression analysis.

Hedonic price techniques may be of some use in estimating benefits of water quality improvement to owners of farms and property along rivers since markets exist for farms and houses. However, there may be some problems at the practical level with hedonic price techniques. First, one needs to gather information on characteristics of land and houses. But usually one does not know what the relevant characteristics of the product (e.g., house, farm, etc.) are *a priori*. As Griliches (1971) put it, the selection of the relevant characteristics becomes an empirical question. Hence, one should gather information on as many characteristics as possible of the particular commodity and then determine the significant characteristics. Second, the nature of the functional relationship between say the price of farmland and its characteristics may not be known a priori and thus the analyst should be prepared to experiment with different functional forms. The hedonic price technique may be used to estimate benefits of water quality improvements in situations when the beneficiaries of water quality improvements are property owners. In other cases, however, it does not appear to be useful.

Epp and Al-Ani (1979) used the hedonic price technique to analyze the effect of water quality on rural non-farm residential property values using a paired sample consisting of 12 clean streams and 13 polluted streams in Pennsylvania. A site located less than two miles from a water quality sampling station, consisting mainly of rural non-farm small communities, was selected on each stream. Data on properties containing one single family, owner occupied dwelling, ownership of which was changed between 1969 and 1976, were gathered for these sites from public records and telephone interviews with current property owners. The study included only properties occupied by the owners all year round and located within 700 feet of the stream.

Multiple regression analysis was used to isolate the effects of water quality and other independent variables upon property sales value for a pooled sample (212 property observations, 93 from clean streams and 119 from polluted) and a paired sample. Analysis of the pooled sample showed that water quality makes a significant difference in the sales value of a rural property. The water quality variable found to be most significant in the regression model was acidity (pH). The authors tried to incorporate pH, dissolved oxygen, biochemical oxygen demand, acid from minerals, acid from carbon dioxide, nitrates, and phosphate concentrations in the regression model. Only the three measure of acidity had consistently significant effects on property values. The authors also tried a general measure of water quality based on the perception of the property owner determined in the survey in the regression model as an alternative measure of water quality and found this variable (which was entered as a dummy variable in the regression model (polluted = 0, otherwise = 1)) also to have a significant effect on property values.

The study by Epp and Al-Ani is based on sound economic theory. It gives a monetary measure of the effect of water quality on property values. The study also incorporated water quality on property values. The study also incorporated water quality variables in the variation model. However, the nonsignificance of relevant water quality variables like dissolved oxygen in the regression model requires more explanation.

The Damage Method

The damage method is one of the approaches used to estimate foregone benefits to water users due to water quality deterioration. Essentially, the damage method attempts to measure the reduction in the value of water-using activity as the level of some pollutant in the water is increased. There have been few studies that applied the damage method. The major handicap in using the damage approach is obtaining information that relates water quality deterioration to dollar damages or physical damages.

Dow Chemical Company (1972) reported the findings of a study that was specifically concerned with sediment as a water quality variable. The study estimated the economic impact of sediment on water uses for the Potomac River. Nine types of water uses were identified and damages to each type of water use estimated. It was found that a one ton increase of sediment per year in the Potomac river would reduce aesthetic valuation, commercial fishing, and recreational fishing by $2.56, [illegible], and [illegible], respectively.

It appears, however, the Dow Chemical Company study on recreation is methodologically deficient. First, the number of recreational fishing days were estimates obtained from the Fish and Wildlife forecasts, not actual or expected number of visists by the recreationist himself. Second, the study assumes an average value for a day of fishing rather than obtaining the estimates from the users themselves. In addition, the study assumes that the damage functions are linear and this point may be debatable. Finally, the study concentrated on sediment as a water quality variable. While it is true that sediment is an important determinant of water quality it is not the only one.

The Bidding Game Technique

Bradford (1970) developed the theoretical basis of the bidding game technique for obtaining benefit estimates of public goods through the derivation of individual bid curves. Individual bid curves show the maximum amount of bid in terms of a private good (money) that an individual is prepared to willingly offer for changes in the quantity of a public good. The slope of the individual bid curve at any point gives the individual's marginal rate of substitution of the private good (e.g., money) that individuals are prepared to offer for a public good (e.g., water quality). The aggregate bid curve is obtained by adding individual bid curves for a given level of a public good.

The bidding game technique has been applied to a few environmental quality studies. Some examples are Randall, Ives, and Eastman (1974); Brookshire, Ives, and Schultze (1976); and Rove, D'Arge, and Brookshire (1980).

Randall et al. (1974) estimated the benefits that may be gained from abatement of aesthetic environmental damages (reduced visibility) associated with the Four Corners Power Plant and Navajo Mine in New Mexico. Three levels (A, B, and C) of aesthetic pollution were considered. Level A represented extreme aesthetic pollution, and B represented moderate pollution, while C depicted the least pollution. Sales tax bidding game,[2] electricity bill bidding game,[3] and user fee bidding game[4] were designed to elicit the highest amount of money which respondents would be willing to bid to improve the environmental quality from a lower quality level (depicted by a photograph) to a higher quality level (depicted by a photograph).

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[2] Individuals were asked how much increase in their sales tax they were willing to bid to improve visibility.

Three groups of people were selected to be interviewed. These were (1) residents of the Indian Reservation, mainly Navajos; (2) residents of non-reservation sections of the region, and (3) tourists and recreationists who visit the area. The sales bidding game was used to determine the bids of the reservation residents. For the non-reservation residents of the region, both the sales tax and the electricity bill bidding games were used. The user fee bidding game was used to obtain the bid of tourists and recreationists in the area. Different bidding games were used to make the bids (payment to abate pollution) less hypothetical to the three groups of people selected. The estimated consumer aggregate bid was found to be $11.25 million annually to improve environmental pollution from A to B, and $19.31 million annually to improve environmental quality from B to C.

The bidding game technique is based on sound economic theory. However, the use of bidding games has not been without question. For example, Samuelson (1947) questioned the use of bids as representing willingness to pay for public goods. In addition, Samuelson (1954) has questioned the usefulness of voluntary approaches (e.g., bidding game) in general to obtain true willingness to pay of beneficiaries. This criticism, however, applies to all voluntary approaches that are employed to obtain benefit estimates of public goods, not only bidding game technique. The major concern with bidding games are reliability of bids (problems of bias). Clearly, better questionnaire design, large samples,and research into ways of eliciting responses on bids are essential to obtain more reliable estimates.

NON-USER BENEFITS

Most studies that estimated recreational benefits in the past concentrated on the benefits that users of recreational facilities derive from these facilities. However, this emphasis on the user population has ignored the values that non-users of recreational facilities attach to the quality of these facilities. In this sense, benefit estimates based on users alone may underestimate social benefits.

Krutilla (1967) referred to benefits accruing to non-users of recreational facilities as preservation benefits. It is believed that there are at least three different kinds of non-user benefits from improving the quality of natural environments. These are option value, bequest value, and existence value. Weisbrod (1964) is credited with the concept of option value. The latter two are due to Krutilla.

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[3] Individuals were asked how much increase in their electricity bills they would pay to improve visibility.

[4] Individuals were asked how much increase in their user fees they would pay to improve visibility.

According to Weisbrod, option demand exists when the demand for a commodity is characterized by infrequency of use and uncertainty of future use, and the cost of making the commodity available once production has been discontinued is very high. As examples, Weisbrod points to cutting down the redwoods in the Sequoia National Park, discontinuing hospital services, and urban transit. To this list one may add polluting natural environments such as rivers. Option value refers to the amount of money that individuals who are not currently using a facility are willing to pay to have the option of using it later on.

Krutilla (1967) and Henry (1974) define bequest value as the present generation's willingness to pay for preserving the quality of the natural environment for future generations. Existence value is defined as the value that non-users of natural environments attach to the mere knowledge of their existence.

It should be noted that option value, bequest value, and existence value are important in decision making only if the services of the natural environment are to be discontinued. In that case, the benefits foregone are not only those of individuals who do not use the services but attach values to the availability of the services in the future for themselves and the following generations. Thus, if the Egyptians decide to tear down the pyramids and use them for home construction, the foregone benefits are not only the losses to foreign tourists and Egyptians who prefer to preserve the pyramids; losses accrue to all other people who derive satisfaction from the knowledge that the pyramids are there and will be there in the future.

However, option value, existence value, and bequest value seem to be less important when the supply of the natural environment is not threatened. Thus, to the extent that non-users of natural environment are certain that the services would be there when needed, they will be less likely to pay for them. Farmers would not buy hail insurance if they were certain there would be no hail. The point is that option value and preservation values may be omitted from benefit computations of environmental quality improvements if that service is certain to be provided, but they should be included in the decision to discontinue provision of the service.

There have been few attempts to empirically apply option value, bequest value, and existence value. Walsh and co-authors (1978) applied the concepts of option demand and preservation demand in the valuation of water quality improvements in the South Platte River due to irreversible mineral and energy development pollution. The study interviewed 202 resident households in Denver and Fort Collins, Colorado, using the bidding game technique. Photographs were used to depict different water quality levels in eliciting willingness to pay for water quality improvements. It was found that the willingness to pay for the option to engage in water recreation in the future was $22.60 per year. In addition, the study found that nonusers of the South Platte River were willing to pay $16.97 for bequest value per year, while the annual willingness to pay for existence value of nonusers was found to $24.98. The study provides willingness to pay from one water quality level to another, but does not relate the willingness to pay to any particular water quality variable.

WITHDRAWAL OR DIVERSION USE BENEFITS

This section looks at empirical benefit studies that attempted to estimate the benefit of water quality improvement for diversion or withdrawal uses. Diversion uses include municipal water supply, industrial and agricultural uses.

Municipal Benefits

The presence of pollutants in rivers that supply homes with drinking water imposes costs on the consumer. An individual or collective effort to reduce the level of pollution in drinking water raises the water value and, if consumers are rational, more willingness to pay. A rational consumer would be willing to incur cost to improve water quality to avoid damages to his appliances, pipes, and other household items that come in contact with water used in the home, if this cost is less than the damage he would suffer without improving the water quality.

There have been very few studies that attempted to measure the economic damages to household items due to municipal water supply damages. Tihansky (1973) developed a comprehensive framework for analyzing national mineralized water supply damages. Tihansky reasoned that mineralized water increases the rate of depreciation of household items and increases the cost of home appliance repair. Individual damage function relating physical damage to each type of household appliance and water distribution facility due to mineral and other constituents of water were derived. Data from household surveys on depreciation and operating problems enabled Tihansky to translate individual damage functions into ranges of economic losses. After derivation of individual monetary damage functions, Tihansky applied these individual monetary damage functions to state household statistics such as income levels and water quality to obtain state, regional, and national damages estimates due to mineralized supply water. He found significant damage estimates in the Midwest and Southwest. The average national damage was found to be $33.50 per year per household.

Tihansky derived his damage estimates from a model that is based on sound economic theory. He also provided a monetary measure of foregone benefits due to the presence of minerals in domestic water supply. The study developed functions relating damage to a water quality variable (total dissolved solids). However, the problem of the reliability of the estimates and the appropriateness of using only a single water quality variable remains.

Industrial Benefits

Water is an input in most industrial production processes. In some cases the quality of water as an input may be unimportant. In other cases, quality of water is critical. For example, soft drink makers, breweries, and food processors are among some of the industries that need high quality water. These industries incur additional cost to improve the quality of the water to an acceptable standard. To these industries deterioration in water quality means higher costs of production and lower profits.

The benefit of water quality improvement to industrial enterprises is the cost savings that results due to reduced treatment costs. Thus, the proper procedure for estimating benefits of industrial benefits is to estimate the cost savings associated with different levels of water quality. Industrial benefit estimates associated with different levels of salinity in the Lower Colorado River were made by U.S. Environmental Protection Agency (1971) and U.S. Department of Interior (1974). The U.S. Environmental Protection Agency (1971) found that a 1 mg/l increase in salinity in the Lower Colorado River imposes an income penalty of $1,148 annually on industry. The Department of Interior estimated the penalty to be $1500 annually.

Agricultural Benefits

To estimate agricultural benefits from water quality improvements, one needs a function relating net revenues to water quality for each crop in each river basin. From this relationship, one can estimate agricultural benefits as being equal to the difference in net farm income between the two levels of water quality. The problem, however, is that in most cases the crop yields and production costs at different water quality levels are unknown. In addition, water quality is multi-dimensional and even deriving functions relating net income to a particular water quality variable, say, sediment, can be difficult. But, if several water quality variables are involved, the task may be greatly complicated.

A search of the literature revealed some studies relating yield to salinity for major crops. Some examples are Sun (1972), Ayres (1977), and Christiansen, Olsen, and Willardson (1977). The study by Ayres provides the levels of salinity associated with 0, 10, 25, and 50 percent reductions in expected yields for field crops, fruit crops, vegetable crops, and forage crops. Christiansen and others (1977) provided an evaluation of using salinity as the only water quality parameter in determining the quality of irrigation water. They recommended that water quality evaluation be based on complete chemical analysis and quality information be provided on other water quality parameters such as nitrate-nitrogen.

Sun (1972) analyzed the effect of irrigation water quantity and quality on agricultural production in the Imperial Valley of California. In this study Sun derived functions relating yield to water quality variable (salinity) for each of the major crops grown in the Imperial Valley of California for four salinity levels (480, 960, 1280, and 1920 mg/liter).

In addition, Sun derived farm, firm, and regional production functions where income is the dependent variable and water quality and quantity are the independent variables. Sun determined that for the 189,000 hectares (469,200 acres) in the Imperial Valley in 1970, there would be an estimated $0.12 per hectare ($0.05 per acre) reduction in annual net farm income if the salinity were allowed to increase by 1 mg/liter.

The Department of Interior (1974) also made agricultural damage estimates due to increasing salinity in the Lower Colorado River using the Sun (1972) model and an input-output model developed by the U.S. Environmental Protection Agency (1971).

Other economic studies have estimated the social cost of alternative water quality improvement policies on the agricultural sector (Kraft, 1975; Pfeiffer, 1976; Pfeiffer and Whittlesey, 1976). However, few studies have attempted to measure the social benefit of water quality improvements in an irrigated river basin in a rigorous fashion.

Other Relevant Benefit Studies

This section has concentrated on empirical studies that attempted to estimate benefits of water quality improvements. However, benefit-cost analysis has been applied to a variety of projects ranging from water resources development to research and development projects. While it is neither the purpose nor the intention of this study to review all such works, it would be a disservice to the reader not to mention a few of the major works. The interested reader may find Dasgupta and Pearce (1972), Peskin and Seskin (1975), Mishan (1976), Freeman (1979), and Sinden and Worrell (1979) of some help in understanding the economic concept of benefits. This review benefited from these works. At the empirical level the interested reader may find Dorfman (1965) useful. In addition, the survey articles by Prest and Turvey (1964) and Currie, Murphy, and Schmitz (1971) provide good references on actual benefit studies.

SUMMARY

This section briefly sketched the origin and the development of the benefit concept as it relates to the measurement of social capital value. The value of a good consists of the price of the good plus a surplus amount which the consumer of the good freely enjoys. Dupuit's (1844) contribution to economics is in recognizing the existence of this surplus amount which the consumer freely enjoys and incorporating it in the valuation of goods. Specifically, Dupuit defined the benefit of a good as the maximum amount of money that the consumer would be willing to pay rather than forego the use of the good. The last portion of the historical sketch briefly looked at the efforts of various agencies in attempting to apply the economic concept of benefit.

This study established three criteria that a benefit study should fulfill. First, the study should be firmly grounded in economic theory. Second, the study should provide monetary valuation of the benefits. Third, water quality variables must directly enter the analysis. The empirical benefit studies reviewed were judged on these criteria.

This section selectively reviewed benefit studies in the area of water quality. The review was organized on the basis of water uses. For each type of water use, the review presented an inventory of approaches that have been used by different analysts in estimating benefits for that particular use.

The review of the empirical benefit studies showed that the majority of the studies failed to incorporate water quality variables in their analyses. The ones that incorporated water quality used only one water quality variable as being representative for water quality in the river. This, however, is unrealistic in that water quality is a multidimensional variable. Also, many of the empirical benefit studies were conceptually defective, i.e., they lacked theoretical support for their work.

In conclusion, the most serious challenge facing analysts in estimating benefits of water quality improvements (pollution abatement) is incorporating water quality variables in the analysis as this review showed. There still remain many problems of accurately measuring the value of benefits, however, even after solving the technical problems of relating pollutant levels to water quality definitions.

SECTION 4

THEORETICAL BACKGROUND

This section discusses economic concepts relevant to the conceptual understanding and empirical measurement of benefits from pollution abatement. First, the concept of benefit is discussed. Next, the failure of the market economy to price environmental services necessitates a rational explanation of this phenomenon. Neoclassical economics rationalizes the existence of this situation using the concept of externalities. The discussion of externalities provides a theoretical insight into the causes and welfare implications of water pollution.

The need to resolve resource misallocations resulting from water pollution leads to ways of internalizing the externalities created by pollutants in common property waters. Finally, methods of estimating benefits of extra-market goods are discussed. Two benefit measures, the willingness to pay and minimum acceptable compensation measures, are emphasized. An evaluation of the available approaches for estimating benefits in the absence of market prices is made.

THE ECONOMIC CONCEPT OF BENEFIT

Basic to the economic concept of a benefit is a commodity (a good, or a service). According to Sinden and Worrell (1979), benefit is a value index of an economic commodity to some person in terms of another commodity, usually money. The term benefit has meaning and a cardinal magnitude only if there is an underlying economic commodity that someone wants. In economics, money is the universal measuring rod of value and, hence, the benefit that people derive from commodities is measured in terms of money. It should be noted that there is an exchange rate between money and other commodities and between the commodities themselves in terms of money. Money has value because it commands other commodities in exchange. In short, a benefit is the measure of an economic value to the recipient of the commodity.

The theoretical literature (Hicks, 1956; Mishan, 1976) suggests two alternative benefit measures, based on individual valuation. The first measure defines the benefit that a person derives from the use of an economic commodity to be the maximum amount of money that the individual is willing and able to pay for the commodity, while maintaining his initial welfare position. This will be referred to as the willingness to pay measure. The second measure defines the benefit that a person foregoes from willingly giving up the use of a commodity to be the minimum amount of money that the individual requires in compensation, while maintaining his initial welfare position. This will be referred to as the minimum acceptable compensation measure. For small changes, in a perfectly competitive market,[1] the two benefit measures would be equal, and in turn equal to the market price of the commodity.

For empirical work, to derive the monetary value of a commodity (benefit) to consumers, one uses the market demand curve (Marshallian Demand Curve) of the commodity. The market demand curve shows the various quantities of the commodity that are purchased at different prices. Figure 3 shows the market demand and supply curves for a commodity, assumed to be linear for ease of presentation. Note that one can also interpret a demand curve as depicting a gain-sacrifice combination for consumers. This can be demonstrated by using the demand curve in Fig. 3. For example, the price axis may be viewed as the value of what is sacrificed or given up and the quantity axis as what is gained. Thus, in Fig. 3, consumers are willing to give up OP units of money for the last unit of the commodity if the available quantity is QQ. If the quantity of the commodity is increased from QQ to QQ_1, consumers are willing to give up OP_1 units of money for the last unit of the commodity. Similarly, if the quantity of the commodity is increased to QQ_2, consumers are willing to give up OP_2 units of money for the last unit of the commodity. The unit benefits or the marginal utility of the commodity decrease as the quantity of the commodity is increased.

In Fig. 3, the market price for the commodity is OP_2 where the total expenditure for consuming QQ_2 units of the commodity is the rectangle OP_2DQ_2. However, consumers actually derive more benefits than indicated by this area. In fact, consumers derive benefits equivalent to $OADQ^2$. The unpaid portion of the benefits represented by AP_2D is called consumer's surplus. Thus, market prices underestimate benefits by the amount of consumer's surplus unless the demand curve in Fig. 3 is horizontal.

If the demand curve is viewed as a marginal benefit curve, the area under the demand curve represents consumer benefits. Let

$$P = f(X) \tag{4.1}$$

be an inverse partial function, where X is the commodity and P is the price of the commodity. The benefits (B) associated with increasing the quantity from X_0 to X_1 is given as

$$B = \sum_{X_0}^{X} f(X)dx \tag{4.2}$$

where dx is a small incremental change in quantity.

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[1] A perfectly competitive market is characterized by many buyers and sellers, homogeneous products, perfect information, and freedom to enter and exit the market.

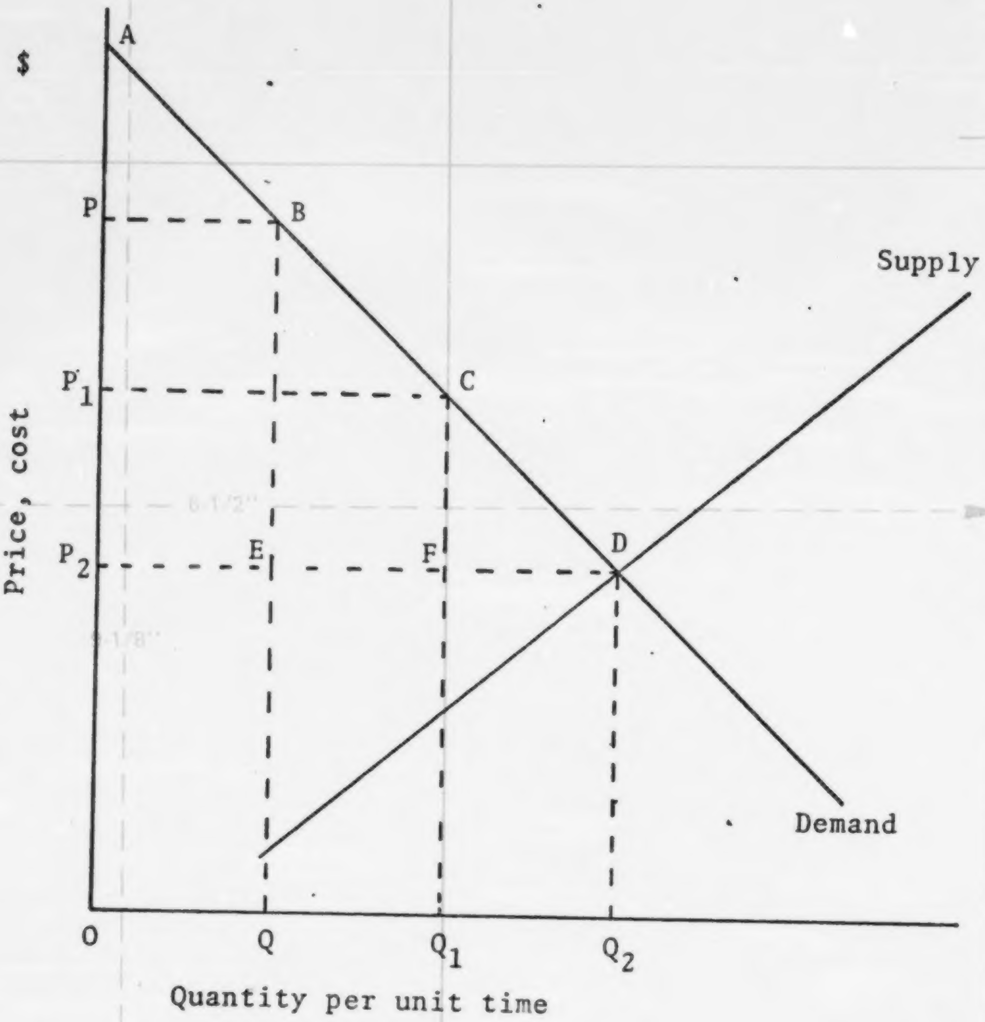

Figure 3. Supply and demand curves for a hypothetical economic commodity.

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Theoretically, the correct measure of benefits is not the area under the market demand curve (Marshallian Demand Curve) given by Equation 4.2. Instead, it is the area under the compensated demand curve (Hicksian Compensated Demand Curve). The compensated demand curve for a commodity is derived by holding consumer utility constant. The area under the market demand and compensated demand curves are identical when income effects are zero. In empirical work, however, the observable market demand curves are used to estimate benefits since compensated demand curves are unobservable.

Given the various market price and quantity combinations for a commodity, the estimation of the demand function is an econometric problem. Problems of benefit estimation arise when the demand function cannot be estimated because of lack of price and quantity information. For example, the private market does not provide prices for water quality even though the demand for it is increasing and it is considered to be a superior good[2] (Kneese and Bower, 1972; Dorfman, 1977). This question is the subject of the next major section.

RESOURCE ALLOCATION THEORY AND WATER QUALITY MANAGEMENT

Water resources experience quality degradation because the market fails to allocate resources to maintain their quality. Bator (1958) defines market failure as "the failure of a more or less idealized system of price market institutions to sustain 'desirable' activities or to stop 'undesirable' activities." Society views maintaining water quality as "desirable" activities (U.S. Congress, 1972, 1977) and increased level of pollution as "undesirable" activities (Erskine, 1972a).

Bator suggests that a perfectly competitive market may exhibit market failure in five ways:

1. By existence--when there are no market prices that will accurately reflect the maximization of a social welfare funcion by being equated to a set of marginal rates of substitution.

2. By signal--when the price system leads profit-maximizing entrepreneurs to a position of local profit maximum instead of the maximum maximorum.

3. By incentive--when the market system allows negative profits in some socially desirable enterprises.

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[2] A superior good is an economic good for which the quantity demanded rises more than in proportion to increases in income. A superior good has income elasticity of demand (η) greater than unity. That is,

$\eta = \frac{\partial Y}{\partial I} \frac{I}{Y} > 1$ where Y and I are water quality and income, respectively, and ∂Y and ∂ are small changes in water quality and income, respectively.

4. By structure--when self-policing perfect competition is not present, then prices will not lead to a pareto optimal economic organization.

5. By enforcement--when there is some arbitrary legal or organizational imperfection in the market that prevents the proper prices for inputs and outputs from being introduced into the profit-maximizing production decisions or utility maximizing consumption decisions.

Bator has proposed that the five ways by which a market exhibits market failure are due to three possible, but not mutually exclusive causes. These causes are ownership, technical, and public good externalities.

Ownership externalities arise when the owner of the factor of production cannot charge for the value of its services because of legal, institutional, and other reasons. The mode of market failure is by enforcement.

Technical externalities arise because of either indivisiblities or increasing returns to scale. There are kinks in the firm's cost curve with indivisibilities. Production may occur when price equals marginal cost and exceeds average cost; this position may represent a local profit maximum instead of a maximum maximorum. With indivisibilities present, the mode of market failure is by signal. The price system fails to lead enterpreneurs to optimum profit levels. On the other hand, with increasing returns to scale, marginal cost pricing produces losses since marginal cost is less than average cost throughout. Here, the market creates negative profits (price is less than average cost) in desirable industries. The mode of market failure with increasing returns is by incentive. The market system allows negative profits in socially desirable enterprises. Increasing returns normally lead to monopoly. The market fails by structure.

Public goods externalities arise when an individual's consumption of a good leads to no reduction from any other individual's use of the good. As a result, there is no need to ration public goods between individuals since no set of market prices is useful for individual production and/or consumption decisions. There is no set of market prices which will efficiently ration a fixed bill of public goods. Thus, a private market for public goods fails by existence.

Davidson et al.(1966) have shown how ownership, technical, and public goods externalities contribute to the failure of the private market to allocate resources for maintaining water quality.[3] A river draining an irrigated basin may cover a large geographic area and pass through the property of many individuals, firms, and governmental units. Consequently, water use and waste disposal by one unit can have a direct effect on the operation of others (Kneese, 1962). Normally, upstream water users are not forced to pay for reducing the quality of the water that is passed on downstream. Consequently, the market fails by enforcement because of ownership externality. Water is a fugitive resource, and it is not easy to establish legal property rights over it. Without defined private property rights, upstream water users cannot collect payments from the downstream beneficiaries of water quality improvements nor would they compensate the downstream users for water quality management in any multiple use river basin.

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[3] Hall (1972 applied the discussion set forth by Davidson and coauthors to environmental amenity.

Technical externalities contribute to the failure of the private market in water quality provision. A water resource such as a river is usually the major or only source of water in an irrigated river basin. A free market to allocate resources to water quality management would fail by structure (because of monopoly pricing). It would also fail by signal and incentive due to increasing returns to scale and indivisibilities in the production of water quality for various uses.

Public goods externalities also contribute to the failure of the private market in water quality provision. The mode of market failure is by existence. The market fails because no set of market prices can reflect benefits derived from water quality. No set of market prices can be derived because a river is a multiple use resource and some of the potential users may have option demand for it. An option demand refers to the option to consume the commodity in the future (Weisbord, 1964). Provision of the option to consume the good in the future is a pure public good in that the option to consume in the future may be enjoyed by all persons simultaneously, and one person's consumption of it (the option to consume) does not reduce the consumption opportunities for others.

Weisbord (1964) indicated that commodities having option demand have three principal characteristics: (1) infrequency and uncertainty of consumption by individual consumers, (2) costliness of reinitializing or increasing production of the commodity once it has been curtailed, and (3) non-storability of product (that is, inventory of the product from off-peak demand period cannot be carried over to compensate for shortages which might occur during periods of peak demand).

Davidson and co-authors (1966) have realized that many goods (e.g., demand for durables) possess the characteristics of infrequency and uncertainty of purchase by consumers and indivisibilities in production, but do not have a public good nature since the excess production from slack to peak demand periods can be carried over at relatively low cost. Therefore, they do not have characteristics of public goods.

The situation, however, is different for certain water uses such as fishing and recreation. These uses have characteristics of public goods because of the non-storability attribute. Fishing and recreational demand are usually seasonal. Furthermore, the demand for these uses peaks during weekends when most people are not working. However, the quality of the water resource has to be maintained all week even though it may be underutilized during midweek. The services of the water resource that were not used cannot be made available when they are needed during weekends.

Recreational and fishing water uses are affected by option demand. At any given time, only a small proportion of the population is actively engaged in recreation and fishing. Some or all of the non-participants in recreational and fishing water uses currently may consider using the services of river or lake sometime in the future. To ensure the availability of adequate water quality in the future, some of these potential future users (for recreation and fishing) would be willing to pay to have the option of using these services in the future. However, the market for the services of a water resource does not take account of this future demand. Thus, to the extent that option demands are not accounted for, the social value that society places on the services of water may be underestimated. This is particularly important when decisions regarding increases in supply of certain water uses are made.

Davidson and co-authors (1966) also have identified another possible cause of a public good externality in the provision of fishing and recreational services called "learning-by-doing." It arises from the relationship that exist between present and future uses of water for recreation and fishing. The availability of recreational and fishing opportunities tend to encourage people to engage in these activities. To engage in fishing and recreational activities, however, one needs to acquire certain skills. The availability of recreational and fishing opportunities increase the likelihood of acquiring the necessary skills to engage in these activities. Thus, the demand for these activities tends to increase rapidly over time as individuals learn to enjoy these activities. The present generation's participation and enjoyment of recreational and fishing opportunities will stimulate future demand without reducing the supply presently available.

The discussion in this section has demonstrated how ownership externalities, technical externalities, and public goods externalities render the private market ineffective in allocating resources for the provision of adequate water quality.

INTERNALIZING EXTERNALITIES

The pollution of water constitutes an economic problem in resource allocation because downstream water users suffer uncompensated welfare losses. Specifically, it is an economic problem according to Burrows (1980, p. 2) because "the means by which pollution can be reduced are themselves resource using." Reducing pollution has its social costs (abatement costs). On the other hand, not reducing pollution also has social costs in terms of its adverse effects on people. To maximize social welfare, society has to make choices between abating and not abating pollution. However, the discussion in the preceding section showed that the current market arrangement does not provide adequate incentives for abating water pollution.

Many economists have suggested alternative ways of internalizing externalities that are created in the processes of production and consumption (Pigou, 1962; Coase, 1960; Davis and Whinston, 1962; Mishan, 1971; Meades, 1952; Baumol, 1972; Baumol and Oates, 1979). Approaches suggested by economists for correcting externality problems can be grouped into two categories.

They are decentralized approaches and centralized approaches. Examples of decentralized approaches are private bargaining between the concerned parties, merger of the affecting and affected parties into one economic unit, and auctioning of pollution rights. For a decentralized approach to internalize externalities, property rights need to be assigned and enforced.

Examples of centralized approaches to internalizing externality problems include taxation, subsidy regulations, and standards. Centralized approaches are political solutions to externality problems. They attempt to create incentives to control pollution through the political power of the state over the individual. Of the centralized approaches for internalizing externalities, most economists tend to prefer the residual charge or taxation scheme. This is because it provides incentives to residual emitting economic agents to clean up pollution they create, but it neither tells them how to go about it nor does it force each to respond in the same way or same degree. In short, according to Fletcher (1977), it is preferred because of the flexibility it provides.

The residual taxation scheme, however, assumes that the quantity of the externality that each emitter of residuals produces is known. This is true for point source pollution where the source and quantity of pollution produced is known. However, in certain types of pollution neither the precise source (individual emitter) nor the quantity of pollution produced by each individual is known. A good exmple of this latter case is irrigation return flow pollution. It is difficult to determine the amount of pollution produced by individual farmers because the quantity of pollution generated depends on slope, soil type, method of irrigation adopted, types of crops grown, and management practices of the individual farmer among other things. Furthermore, the many paths taken by non-point source pollution makes determination of each emitter's contribution difficult. But, without knowing the magnitude of pollution that each farm generates, it is difficult to impose a residual charge or tax to modify the behavior of the individual. Clearly, the charge or taxation scheme is not very useful for controlling non-point source pollution at least until it is economically feasible (the marginal social gains from monitoring exceeds the cost of monitoring pollutant discharge) to measure each emitter's discharge.

Baumol and Oates (1979) have pointed out that the singleminded advocacy of fees or charges to the total exclusion of other environmental policy instruments has gone too far. They believe economists have overlooked the operational problems inherent in a system of fees, particularly the difficulties in measuring levels of emission. Baumol and Oates describe available environmental policy instruments for internalizing externalities.[4] They also analyze both in principle and in practice the strengths and limitations of each policy instrument in achieving particular environmental objectives. Furthermore, Baumol and Oates also rate the performance of the various policy instruments to control pollution based on nine specific criteria.[5] Based on these nine criteria, Baumol and Oates rate the performance of sale of pollution permits and charging fees moderately high. Moral suasion and direct control measures were also given fairly good overall rating. On the other hand, subsidies and government investments as pollution control policy instruments each were given lower ratings. It should be noted that in arriving at such conclusions Baumol and Oates made certain personal judgments that may not receive universal support.

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[4] Baumol and Oates (1979) considered four major policy instruments for pollution control. These are (1) moral suasion; (2) direct controls; (3) market processes; and (4) government investment.

Can ownership externalities, technical externalities, and public goods externalities that blend to cause the private market for water quality to fail be internalized? Ownership externalities that arise because of the fugitive nature of water can be corrected by a policy that integrates the independent water users in the river basin (Bator, 1958; Davidson, 1963). In other words, the different water users throughout the river basin could be merged into one economic unit to internalize all benefits and costs. Integrating the independent water users throughout the river basin eliminates the market failure by enforcement, but leaves technical externalities in the provision of water quality untouched. In addition, it may not be practical to implement. Thus, merging the different water users in the river basin into one economic unit is not sufficient to assure the proper allocation of resources into water quality improvements.

Davidson et al. (1966) have suggested that technical externalities that arise in the production and provision of water quality improvements because of indivisibilities and increasing returns to scale can be corrected by some sort of integrated public utility arrangement with private ownership and a marginal-cost pricing policy with subsidies to make up any deficits. This policy would eliminate market failure due to the presence of technical externalities in the production of water quality improvements. However, the market for water quality fails by existence even after ownership and technical externalities are removed because of the public goods nature of water quality over time. Thus, a private market fails to allocate resources to water quality provisions. Hence, water quality improvements (pollution abatement) in a river basin cannot be left to the private sector. The next section is concerned with the examination and discussion of methods of measuring benefits of water quality improvements in the absence of market prices for water quality improvements.

METHODS OF ESTIMATING BENEFITS IN THE ABSENCE OF MARKET PRICES

The measurement of benefits of private goods poses no theoretical and conceptual problems. This is because the economic good exchanged is clearly defined; the beneficiaries (people who demand the good) are also known; property rights to the good are clearly defined; and the private economy offers sufficient incentives (to economic agents) to operate a private market. In such cases, the commodity prices reflect all costs so that no uncounted externalities exist.

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[5] The criteria used to evaluate the performance of the environmental policy instruments were reliability, permanence, adaptability to growth, resistance to inflation, incentive for improved effort, economy, feasibility without metering, noninterference in private decisions, and actual and potential political attraction.

Water quality improvement is a public good. Two things characterize a pure public good. First, a public good can serve a small or a large number of persons at exactly the same total cost, that is, the marginal cost of an additional user of the public good is zero. For example, once water quality has been improved to a certain level, as long as there is no congestion, the marginal cost of providing the services of the river to an additional fisherman or recreationist is zero. According to Baumol (1977), this characteristic is called jointness in supply. Second, public goods are often characterized by the impossibility of exclusion of anyone from enjoying the benefits of the public goods once they are provided. Thus, it would be difficult to provide different quality water to two water users at the same place and time. In addition, it would be expensive to exclude people from enjoying the services of improved water quality.

The presence of public goods creates allocation problems in a market economy. This is because the competitive market structure allows for the provision of a good or service only when a market can be operated, that is, revenue covers all costs for the good. The pareto optimality conditions for allocation of private and public goods are different (Reder, 1947; Varian 1978). For private goods, the pareto optimal level is determined by equating

$$MRS^{i}_{S_1,S_2} = PR_{S_1,S_2} = MRT_{S_1,S_2} \tag{4.3}$$

where $MRS^{i}_{S_1,S_2}$ is individual i's marginal rate of substitution between private goods S_1 and S_2. $PR_{S_{1},2}$ is the price ratio between S_1 and S_2 and MRT_{S_1,S_2} is the marginal rate of transformation between S_1 and S_2. The $MRS^{i}_{S_1,S_2}$ shows how much individual i is willing to sacrifice of good S_1 to get one more additional unit of good S_2 holding his level of welfare (utility) constant. The $MRS^{i}_{S_1,S_2}$ can be interpreted as individualized prices (Varian, 1978). The MRT_{S_1,S_2} shows the number of units of S_1 that are to be sacrificed by society to produce one more unit of S_2 holding the resource input constant (Kogiku, 1971). The MRT_{S_1,S_2} can be interpreted as the marginal social cost (MSC) of increasing the quantity of S_2 by one unit for a given resource endowment.

The pareto optimality conditions for an efficient allocation of public goods require that

$$(4.4) \qquad \sum_{i=1}^{N} MRS^{i}_{S_3,S_4} = MRT_{S_3,S_4}$$

where $MRS^{i}_{S_3,S_4}$ is individual i's marginal rate of substitutions between public goods S_3 an S_4 and MRT_{S_3,S_4} is the marginal rate of transformation between S_3 and S_4. Notice the difference between Equations 4.3 and 4.4. Equation 4.4 says that at the optimum output of a public good, the sum of the marginal rates of substitutions must be equal to the marginal rate of transformation. In other words, the sum of individual sacrifices (willingness to pay) to obtain an additional unit of a public good must be equal to the social cost of producing it.

Figures 4 and 5 graphically depict the optimum allocation of a private and a public good. Note that for the public good S_3 in Fig. 5, at equilibrium ($\Sigma MRS_i = MRT_{S_1S,S_2}$) all individuals demand the same amount of it ($S_3 = S_3^{\overset{i}{*}}$). This is because one persons's consumption of the good does not preclude another person's consumption. One fisherman's use of a river does not preclude another fisherman's use of the same river. However, this is not to suggest that each person consumes the same amount of the public good. Note also that in Fig. 5, the aggregate marginal rates of substitution for a public good are obtained by adding the individual $MRS^{i}_{S_3,S_4}$ curves vertically. This is because the same quality can be simultaneously consumed by many people. In Fig. 5 the intersection of $\sum_{i=1}^{N} MRS^{i}_{S_3,S_4}$ and MRT_{S_3,S_4} determines the optimum output level of a public good. Each individual's willingness to pay for the optimal level of public good is determined by examining his $MRS^{i}_{S_3,S_4}$. This information could be used to tax the individual in order to provide the optimal level of the public good. This way, each individual pays his true valuation of the public good. For example, in Fig. 5 individual i pays OA and individual i+1 pays OB. A taxation scheme which extracts from each individual his true valuation of the benefits that he receives from a public good is called a Lindahl equilibrium (Varian, 1978).

The empirical determination of the optimum levels of a public good (S_3^* in Fig. 5) is difficult because each consumer's marginal rates of substitution are needed. The marginal rates of substitution for private goods are revealed in the market by consumers' preferences. On the other hand, for public goods like water quality, there are no markets in which consumers can reveal their preferences and marginal rates of substitution. In the absence of markets for public goods, other ways of eliciting consumer preferences for public goods are needed. The literature suggests four

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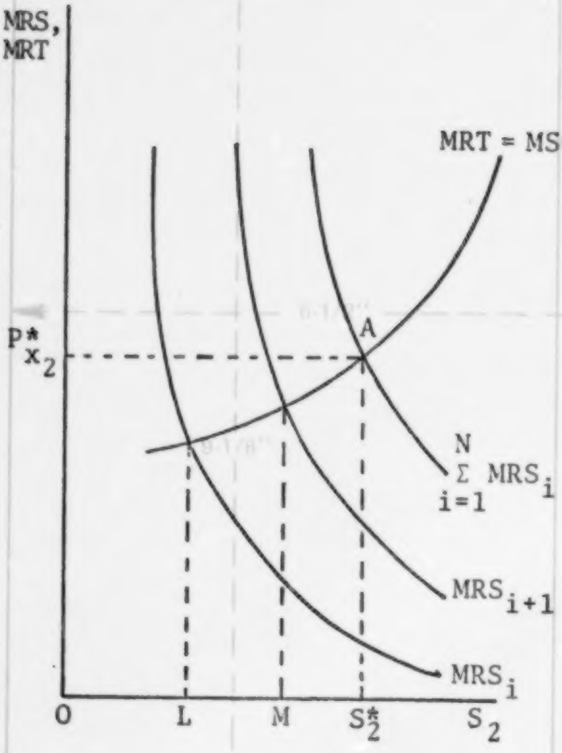
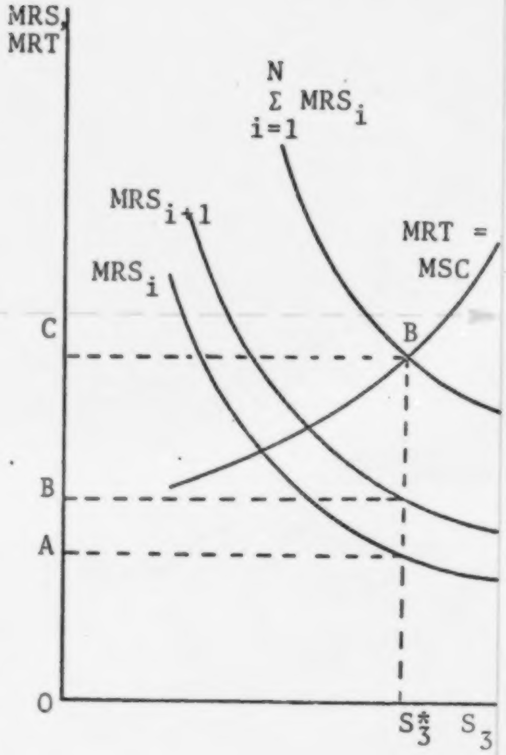


Private good



Public good

Figure 4. Pareto optimum level for a private good (based on horizontal summation of MRS_i).

Figure 5. Pareto optimum level for a public good (based on vertical summation of MRS_i).

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approaches for determining consumer preferences in the absence of markets for public goods (Maler, 1974). These approaches are:

1. Asking consumers how much they are willing to pay for some increase in the supply of the public good in terms of a private good.

2. Voting on the supply of the public good.

3. Indirect methods, based on the relation (elasticities of substitution) between private goods and public goods.

4. Estimating the physical damage from residual emission and evaluating this damage using market prices.

The next four sections describe and analyze these four approaches both in principle and in practice. The discussion emphasizes the first approach for reasons that will become evident later.

Asking Consumers

One way of obtaining the value of a water quality improvement is to ask consumers their willingness to pay for such improvement. The various media of obtaining information can be used. For example, consumers may be contacted by mail, telephone, or personal interviews. The choice of the medium may be influenced by availability of funds among other things. Regardless of the medium chosen, the end result is to elicit the individual consumer's marginal rates of substitution between a private good (money) and the public good (water quality). Thus, the consumer is asked how much he is willing to pay to obtain a given change in water quality. Similarly, the consumer may be asked how much money he would require in compensation for reductions in water quality. According to Freeman (1972), the appropriate benefit measure to be used (willingness to pay or minimum required compensation) depends on property rights. Willingness to pay is an appropriate measure of benefits when property rights to the water supply sources are vested in the polluters. On the other hand, if property rights to the water supply source are vested in the general public other than the polluters then minimum required compensation of the general public is an appropriate benefit measure.

Theoretically, the willingness to pay and necessary compensation for a marginal change in the public good (water quality) should be the same value. That is, if a consumer is willing to pay x dollars for a small improvement in water quality, he should also accept x dollars as a compensation for reducing the water quality to its initial level. In practice, however, it is normally found that empirically estimated values of necessary compensation are larger than values of willingness to pay. For example, see Hammack and Brown (1974); Dwyer, Kelley, and Bowes (1977); and Gordon and Knetsch (1979).

There is no one single accepted explanation in the literature why minimum necessary compensation exceeds willingness to pay. One plausible explanation is that willingness to pay for an economic good is limited by the individual's ability to pay, while for necessary compensation that an individual may seek there is no limit. Hence, for willingness to pay the individual's income and purchase of other goods set an upper limit while for necessary compensation the individual is not bound by any such constraint.

Another plausible explanation is that the difference between required compensation and willingness to pay can be attributed to improper administration of the survey technique which failed to derive the "true" valuation. While this is a plausible explanation, it is unlikely that an error of such a magnitude can be consistently obtained in all empirical studies. Other possible explanations are discussed in Abelson (1979), Gordon and Knetsch (1979), and Dwyer et al. (1977).

A major argument against the use of this approach (asking consumers) is that consumers may not reveal their true valuation (willingness to pay, or minimum acceptable compensation) for a public good. Wicksell (1896) pointed out that consumers have strong incentives to conceal their true valuation (willingness to pay) to obtain benefits at the expense of other consumers, becoming free riders. Samuelson (1954) and Musgrave (1959) concurred with Wicksell and concluded that it is hopeless to expect consumers to reveal their true willingness to pay for public goods. The explanation given is that no one can be excluded once a public good is made available and each person has an incentive to disquise and understate his true willingness to pay.

Before pronouncing all schemes or approaches developed for deriving consumers' willingness to pay as futile efforts, one should realize two things. First and foremost, Samuelson's explanation was a logical abstraction based on a behavioral assumption. To be useful, Samuelson's logical abstraction needs empirical support. Second, one should keep in mind that Samuelson's conclusion applies strictly to pure public goods. According to Samuelson (1954), a pure public good is a good where each person consumes the same amount of the good. In addition, impossibility of the provision of pareto optimal levels of a good is not limited only to public goods, but applies to private goods as well, depending on the assumptions one makes regarding strategic behavior among individual consumers (Smith, 1980). In fact, the various oligopolistic market models are differentiated from each other by the assumptions they make about the strategic behavior of other competitors.

Theoretical Mechanisms for Discovering a True Willingness to Pay

Recent contributors (Clark, 1971; Groves, 1973; Groves and Ledyard, 1977; Smith, 1980) to the theory of public goods are not as pessimistic about the usefulness of voluntary mechanisms in providing public goods. These contributors recognize that incentives do exist for individuals to disguise their true willingness to pay. But, they do not view the situation as being hopeless. In fact, most of them have designed schemes that can,

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supposedly, elicit consumers' true willingness to pay for public goods. Feldman (1980) provides a good summary of some of these schemes.

Clark (1971) and Groves (1973) each independently developed schemes that (1) provide no incentives for individuals to misrepresent their own willingness to pay and (2) lead to pareto optimal levels of public goods. The mechanisms[6] for obtaining individual willingness to pay are designed so that telling the truth is a dominant strategy for each individual. The Clark and Groves schemes for eliciting consumer preferences for public goods, however, have one problem. This problem arises in connection with the disposal of surplus revenue (where sum of individual willingness to pay exceeds cost of providing the public good) that may be generated through taxation to finance the provision of the public goods. If the surplus revenue is returned to consumers, it may create strategic behavior among consumers and may discourage truthful responses for the provision of public goods. On the other hand, if the suplus revenue is not returned to consumers the demand for other commodities is reduced. Thus, the situation may not be pareto optimal.

In general, Hurwicz (1975) has mathematicaly proved that it is not possible to have a scheme that (1) produces pareto optimal levels of public goods, (2) avoids misrepresentation of willingness to pay, and (3) revenue generated exactly equals cost of making the public good available. Note that a problem arises only with regards to disposal of surplus revenue, not misrepresentation of willingness to pay.

Groves and Ledyard (1977) designed a voluntary mechanism that overcomes the problems that the Clark (1971) and the Groves (1973) schemes could not solve--the surplus revenue problem. The Groves and Ledyard scheme produces pareto optimal levels of public good and generates no budget surplus. The scheme, however, breaks down if strategic behavior by individual consumers is allowed.[7] For example, if individual i knows his own desired increment to the public good affects individual j, then individual i may act strategically and optimality may fail. In all cases, where the Cournot-Nash assumption is valid, that is, where individual i assumes his own desired increment to the public good has no effect on other people's desired increments, the Groves-Ledyard scheme works. Unfortunately, these schemes are still in the development stage and have not been applied to a case study yet.

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[6] The mechanisms ask people to indicate utility of the public good or valuation of public good, etc. so a government agency can determine the optimum output of the public good. If individuals give the government agency false messages, the level of public good produced is not optimum and individual utility is not maximized. Hence telling the truth is a dominant strategy for each individual.

[7] The Groves-Ledyard scheme asks individuals to send messages about increased levels of outputs of public goods that they desire. Government agency then determines the optimal level of output of the public good and the individual tax shares for the production of the public good. Each individual maximizes his utility by considering that his actions have no influence on other individuals' desired level of the public good.

At the practical level, Smith (1980) argues that there is much casual evidence to suggest that mechanisms exist for the voluntary provision of public goods. To make his point, Smith points to churches, music halls, libraries, art museums, theatres, and other public facilities that are privately financed by voluntary contributions through fund drives conducted by private societies. For skeptics who say public good problems are large group problems, Smith offers national elections that are voluntarily carried by individuals and no individual voter has any perceptible effect on the common outcome. But the act of voting involves cost (going to the polls, reading and marking ballots, etc.). If traditional public goods theory is correct, Smith claims one should observe little or no voting activity since voting is a public good problem.

However, a large number of people participate in national elections voluntarily without any legal requirement to do so. Smith argues that voluntary mechanisms work whether the public good problem is a small group (e.g., church) or large group (e.g., national elections) problem. This observation is in contrast to the conclusion reached by traditional public goods theoreticians such as Wicksell and Samuelson.

Since the major argument against asking consumers of public goods their willingness to pay concerns the misrepresentation of the true willingness to pay, it is important to know how serious is the bias problem (divergence of true willingness to pay from reported willingness to pay). To settle whether the bias problem is an important empirical issue, one needs a large body of empirical studies. Unfortunately, the literature on the free rider problem (misrepresentation of willingness to pay) is largely theoretical and deductive in nature. Few empirical works on the misrepresentation of preferences exist.

Empirical Experimentation with Willingness To Pay

To shed some light on the problem, one needs to set up experimental situations, similar to what marketing specialists call "consumer clinics" (Baumol, 1977), and observe if public goods can be provided by voluntary contributions. Furthermore, it is also useful to know if individual contributions for the provision of the public goods vary with alternative repayment mechanisms adopted, i.e., does the method chosen for repayment affect an individual's willingness to pay for the public good? These answers provide clues in designing better schemes for eliciting truthful preferences.

Smith (1980) reviewed two empirical studies that used experimental settings to test the validity of the free rider hypothesis in the provision of public goods through voluntary mechanisms. The first experiment was by Sweeny (1973). In this experiment, an individual subject pedalled a bicycle connected to an electric generator. Each individual was in a group of six persons. The group was to maintain bright illumination of light for at least ten minutes by pedalling their bicycles to receive partial course credit for participation. Individual contribution to the provision of the public good (group light) was measured by average pedalling speed (number of revolutions per minute). Even though the mean contributions were signifcantly different from zero, it was found that the mean contributions were less than optimal implying a weak support for the free rider hypothesis.

The second experiment reviewed by Smith (1980) was that of Marwell and Ames (1979). In this experiment each subject allocated an endowment of 225 tokens between a "private exchange" that yielded interest in money and a "group exchange" that also yielded interest in money which depended on the group's total contribution. The group exchange required an average contribution of 100 tokens per subject to yield the optimal allocation. It was found that the mean contribution using groups of 4 and 8 persons was 127.6 tokens for the "group exchange." Once again, the mean contributions to the public good were high and significantly different from zero, but the contributions were less than the optimal by 36.2 percent. The contribution may have been smaller not because the "group exchange" was a public good, but rather because the individual was sure he was going to earn interest if he invested in the "private exchange." On the other hand, he was not sure whether he would earn interest in the public exchange as that depends on how the other members of the group act. Thus, an individual who is risk averse may invest in the "private exchange" to minimize the risk of losing interest payments. Clearly, attitude towards risk would influence how much one is prepared to invest in either exchange. As a result, just because contributions to a "group exchange" are smaller than the optimum individual contributions for the provision of the public good, one cannot infer that the free rider hypothesis is maintained. In fact, if the free rider hypothesis was true one would expect zero contributions from each individual as one cannot be excluded from the services of a public good. Thus, it is irrational for individuals to contribute to the provision of public goods when they can enjoy them for free. Clearly, the wide acceptance of the free rider hypothesis is based on strong theoretical argument instead of rigorous empirical test. For other additional more recent controlled experiments that reached the same conclusions as the study reviewed by Smith in this paragraph, see Marwell and Ames (1981).

A rather serious experiment that employed the voluntary mechanism to obtain estimates of individuals' willingness to pay was that of Bohm (1972). In this experiment, individuals were asked to reveal their willingness to pay to see a video tape of a televison program. Individuals knew that the televison program would be shown to them only if their total reported willingness to pay was greater than the cost of showing the program. The cost of the program was known to the individuals in the experiment. Individuals in the experiment were divided into different groups. They were told that they would be subjected to different repayment requirements. Five separate repayment requirements were identified:

1. $AP_i = RWTP_i$

2. $AP_i = \alpha(RWTP_i)$

3. $AP_i =$ Uncertain

4. $AP_i =$ Fixed amount

5. $AP_i =$ Zero

where AP_i refers to the actual amount of money that individual i is required to pay, $RWTP_i$ is i's reported willingness to pay to see the show, and α is a proportionality constant whose value lies between zero and one.

Bohm found that there was no significant difference in the mean stated willingness to pay among the five groups subjected to five separate experimental repayments schemes. Thus, the Swedish television field experiment provides no support to the free rider hypothesis even in its weak form. This, however, is an evidence of a sort, but not overwhelming proof that understatement is never a problem.

Brookshire, Ives, and Schulze (1976) also addressed the bias problem. They asked different people how much they (the different people) were willing to pay to prevent the scenic and aesthetic degradation associated with a power plant siting on Lake Powell.

Brookshire et al. hypothesized and tested the supposition that if there were biased responses to the willingness to pay question, environmentalists would bias their willingness to pay high (overstate willingness to pay) and nonenvironmentalists would balance their willingness to pay toward zero (understate willingness to pay). The authors deduced that if strategic behavior was important, the frequency distribution of willingness to pay responses would be relatively flat, with a large number of high willingness to pay responses. The authors reported that they could not find support for strategic behavior. In other words, they also arrived at the same conclusion as Bohm.

Another study that addressed the misrepresentation of true willingness to pay was by Rowe, D'Arge, and Brookshire (1980). This study was an experiment in quantifying the economic value of reduced visibility due to power development in the Four Corners Region of Southwest United States by directly asking respondents to reveal their maximum willingness to pay (bid) for preventing reduced visibility in the area. The authors recognized the existence of exogneous and endogenous biases that might influence the valuation response of an individual. However, the concern was with endogenous biases in the survey instrument (questionnaire) since the influences of exogeneous factors to the survey instrument (e.g., income, length of residence in the area, etc.) could be tested. The authors recognized strategic bias, information bias, and hypothetical bias as endogenous bias. Strategic bias was defined as an attempt by any individual to influence the outcome or result of the willingness to pay responses (bids) by not revealing his true

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valuation. Information bias was bias induced by the survey instrument in the individual's response. Hypothetical bias was potential error in the individual response because of not confronting him with a real situation.

The authors asked respondents about their environmental stance, that is, whether the individual was an environmentalist or a developer after each individual provided his maximum willingness to pay. The responses were tested for strategic bias (misrepresentation of true willingness to pay) by entering a dummy variable for environmental stance in regression equations. The authors found that the results yielded no significant dummy variables and thus no strategic bias exists for the willingness to pay responses (bids) obtained by asking people who would be affected by power development in the area. Thus, the study by Rowe et al. (1980) also gives credibility to responses obtained by asking consumers directly about their true valuation for a public good.

In summary, the limited empirical studies reviewed indicate that (1) mean willingness to pay was significantly different from zero, (2) strategic bias was not a significant problem as claimed by public good theoreticians, and (3) in general, willingness to pay is not affected by the method of repayment for a public good. However, one should be cautious not to take these studies as a proof that misrepresentation of willingness to pay for public goods is nonexistent.

Voting

Another possible way of determining individual preferences and valuation of a public good like water quality improvement is through voting. The actual voting mechanism can be designed to elicit voter preferences for different levels of water quality improvements. Thus, voters can be asked to register their preferences for water quality improvements by voting either yes or no. In addition, they could be asked to reveal their willingness to pay for different levels of water quality improvements.

Unfortunately, the actual voting mechanism is designed to seek yes or no responses from voters on specific proposals. Often the decision of the majority of the voters determines whether the public good is provided or not. Since public goods are usually provided directly or indirectly by the government, all voters whether they are for or against the provision of the public good would have to share in the cost of providing the public good. However, the majority derives all the benefit from the provision of the public good. The minority shares in the cost of providing the public good, but does not receive any of the benefits of the public good. The majority receives a subsidy from the minority in the provision of public goods. Thus, majority rule as a decision rule leads to the misallocation of resources (non-pareto optimal economic organization) since the minority incurs uncompensated losses which reduces their welfare.

Unanimity as a decision rule allocates resources efficiently (pareto optimal). This is because all voters must vote yes for any public good to be provided at all. Assuming the cost of providing the public good is known, individuals would vote yes only if the benefit that they receive from the public good exceeds their share of the cost of providing the public good. A major problem of implementing unanimity rule is that the cost of reaching a unanimous decision may be prohibitive (Buchanan and Tullock, 1962). Voting as an operational mechanism for obtaining benefit information for public goods like water quality appears to be of limited practical use at least for now.

Relations between Market and Public Goods

Another possible approach for estimating the benefits of extra-market goods (e.g., water quality improvements) is to make use of complementary and substitution relationships that may exist between the public good and some market goods (Maler, 1974). To use this approach, one needs a priori information on the elasticity of substitution between the public good and another market good in the consumer's consumption bundle. That is, both the public and market good are contained in the consumer's utility function. If the two goods are perfect substitutes, the elasticity of substituion between the two goods approaches infinity. On the other hand, when the two goods are perfect complements, the elasticity of substitution approaches zero. In other cases, when the market good and public good are neither perfect substitutes nor perfect complements the elasticity of substitution may range between zero and infinity.

One can derive the demand price for the public good from a knowledge of the demand for a private good when the two goods are perfect complements and perfect substitutes. This approach is restrictive in that it can be used only when the elasticity of substitution between a private good and a public good is either zero or infinity, but cannot be used when the elasticity of substitution lies between these two extremes.

Maler, however, counsels that one should not give up hope. He points out that what is needed is actually weak complementarity between the two goods. Weak complementarity exists if the demand for a private good is zero, then the demand price (willingness to pay) for the public good will also be zero. If, for example, the private good is swimming in the river, and the public good is water quality of the river, then it is reasonable to assume, Maler maintains, that if a person does not use the river for recreation he is indifferent to water quality improvements. Bouwes and Schneider (1979) assumed weak complementarity to estimate the demand price for the environmental services (e.g., recreation) of Wisconsin lakes.

Maler feels that the weak complementarity condition has very broad applications. A major drawback to the weak complementarity condition, however, is that it cannot be applied to valuation cases where there are option demands. In other words, weak complementarity conditions can be applied to value public goods only when one is prepared to make the assumption that no one is willing to pay anything for the option of consuming a public good later. The concept of option demand was discussed earlier.

Estimating the Physical Damage

Another approach for deriving the benefit of water quality improvements is to estimate the physical damage from water pollution and evaluate this damage using market prices. This approach is based on two assumptions. First, it assumes that the foregone benefits because of water pollution can be measured by the damage the pollution produced. Second, it assumes that there are market prices by which these damages can be transformed into monetary measure. The problem with this approach is that in general it does not take all the adverse effects of water pollution into account as it emphasizes actual physical damages (Maler, 1974). Third, it equates loss of benefits with the cost of replacing or rehabilitating without asking the individual if the compensation for the damages is acceptable or not. For example, if water pollution causes damage to the fishery resources in a river, the damage of the water pollution is estimated to be the cost of lost fish valued at the market price of fish. To a sports fisherman, the market value of the fish probably underestimates the value of fish.

The damage approach may be used only in certain instances where aesthetic values are not involved to provide limits to the range of demand prices for water quality. Thus, the usefulness of this approach as an alternative method for estimating benefits is extremely limited.

EVALUATION OF THE METHODS OF ESTIMATING BENEFITS

The preceding four sections described and analyzed the strengths and weaknesses of some methods of discovering individual valuation of the benefits of water quality both in principle (theoretical) and in practice (empirical aspects). The analysis did not find a single approach without some flaws.

Of the approaches analyzed for eliciting consumer preferences for water quality, only the direct approach of asking consumers their preferences, the indirect approach that exploits the substitutability and complementary relations between a private and a public good to derive consumer preferences for the public good, and the damage approach can be made operational. The damage approach is not very useful because it assumes that the adverse effect of water pollution on all water uses is known and can be valued using market prices. The indirect approach that exploits the relations (primarily the elasticity of substitution) between a private and a public good requires a priori information about the elasticity of substitution between a private good and a public good. It can be applied only under a very restrictive set of conditions which are usually not met. For example, it requires that the private and the public goods be either perfect substitutes, or perfect complements, or the public good be without option demand.

The major weakness of the direct approach is misrepresentation of preferences for the public good. The discussion of the direct approach showed that this problem is not as serious as critics of this approach claim it to be. Thus, despite its weaknesses, the direct approach of asking consumers their preferences for water quality improvements seems to be the preferred approach. This study used the direct approach to elicit individuals' marginal rates of substitution between water quality (a public good) and some private good (money). This information on individual marginal rates of substitution between water quality and money will be used to derive the benefits of water quality improvements.

Bradford (1970) developed the theoretical framework for valuing public goods using the direct approach. He points out that ordinary demand curves have not proved as useful analytical tools in models of public good output determination as they have in conventional price theory. Bradford gave two reasons. First, the natural situation in the case of public good output determination is that individuals respond not to a parametric price per unit of public good, but rather bargain over the total quantity of the public good. Thus, average outlays per unit (average revenue) of public good is not interesting. Second, in the case of public goods, more is not an increase in the number of identical units of something, as in the case of conventional private goods, but is rather in the nature of quality improvements. Bradford has pointed out that this difference in the nature of the variable on the horizontal axis (public good) has one implication, that there is no tendency for a unique price per unit of the public good to emerge in a market.

Bradford has suggested using a demand curve-like construction which he dubbed an "aggregate bid curve" for valuing public goods. The concept of the "aggregate bid curve" gives answers to the questions, what is the maximum total amount in real goods or money that society is prepared to give up to obtain a small change in the provision of a public good? The "aggregate bid curve" also gives answers to the question, what is the minimum total amount in real goods or money that society is prepared to accept as compensation for a small reduction in a public good? Clearly, the "aggregate bid curve" concept is a very useful analytical tool. The next logical question is how to obtain the aggregate bid curve. The derivation of the aggregate bid curve will be demonstrated by using a specific public good (water quality as an example).

Assume that each individual has preferences on the consumption bundle that he faces. Thus, the consumer can order the set of consumption bundles. Assume for ease of graphical exposition [illegible] which the individual preferences are def[illegible] Let Y be a public good (e.g., water quality) and let X be all other goods. Thus, the individuals have a utility function which ordinally ranks different combinations of X and Y. That [illegible]

$$u = u(X,Y) \tag{4.5}$$

Let u in Fig. 6 represent an indifference curve for an individual. Assume also that the initial consumption bundle is represented by point A in Fig. 6. Assume the price of good X is one; that is, X is a numeraire good.

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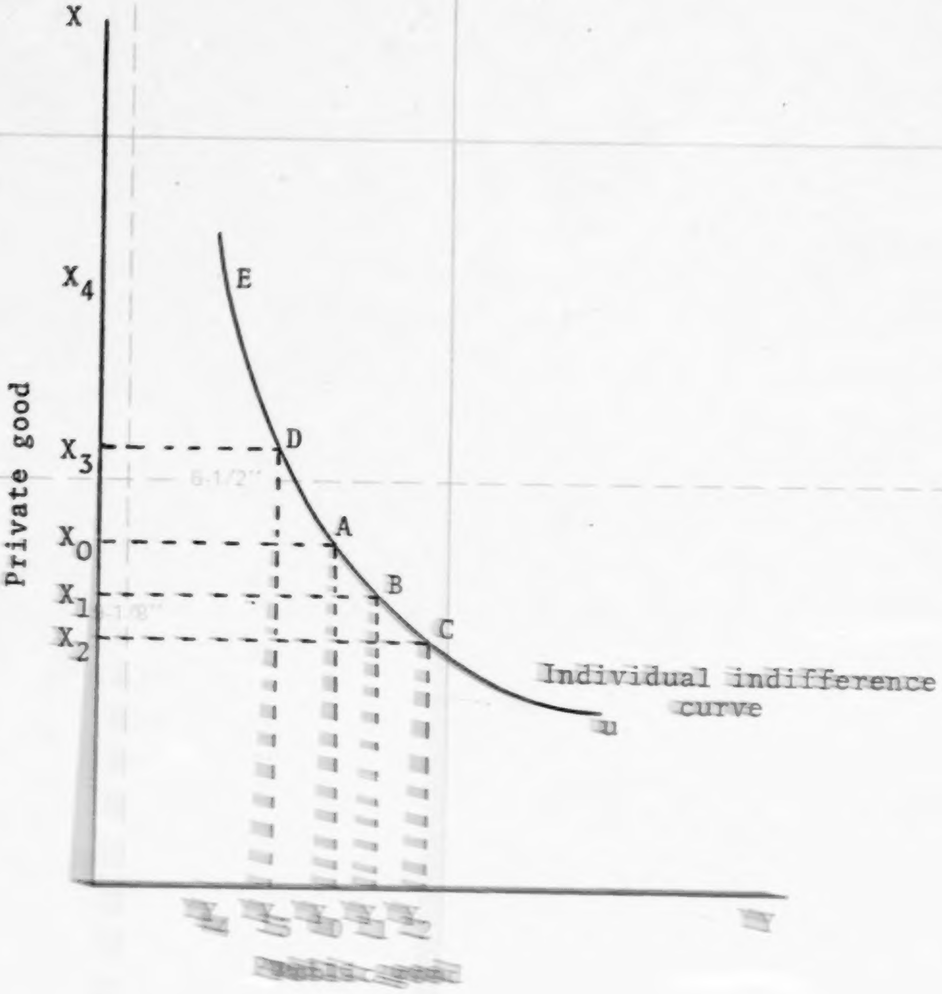

Figure 6. Indifference curve depicting different combinations of a public good and a private good yielding constant utility.

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The problem now is characterizing the pareto optimal consumption bundles of X and Y for individuals and for society. Bradford suggests asking individuals how many units of the private good (X) each individual is willing to bid as a maximum for different possible changes in Y (public good). Figure 7 graphs the relationship between maximum willingness to pay in terms of the private good (ΔX) against changes in the level of public good (ΔY). This relationship (EDABC) in Fig. 7 is referred to as an individual bid curve. The bid curve passes through the origin as an individual would obviously not be willing to pay for no change in the level of public good. A negative bid shows the minimum number of X which would compensate the individual for the indicated change in Y. It should be noted that the individual bid curve in Fig. 7 is the individual indifference curve passing through A in Fig. 6 rotated half a revolution (180°). The slope of an individual bid curve is simply his marginal rate of substitution of the private good for the public good along the given indifference curve. Since the bid curve shows the alternative consumption bundles of X and Y that yield a constant utility, the bid curve also becomes a compensated demand function.

An "aggregate bid curve" shows the maximum total amount of the private good X that individuals can be induced to give up. This amount is obtained by adding individual bids of the private good X. The aggregate bid curve, graphically, is obtained by vertical addition of individual bid curves. Note that the slope of the aggregate bid curve at any point is the sum of individual marginal rates of substitution between X and Y given that all individuals are being kept on the indiffernce curve passing through the initial social state facing society. The initial social state refers to the distribution of private and public goods among members of society prior to the change in the provision of the public good Y.

SUMMARY

This section defined the measurement of a benefit as the maximum amount of money that individuals are willing to give up to obtain better water quality or the minimum amount of money that individuals are willing to accept as a compensation for [illegible]. Strictly, the latter definition is applicable when polluters have the right to discharge pollutants and receiving water supply sources and other water users are not entitled to demand compensation. Since in most cases the situation regarding property rights to the water course is not clear cut, it is useful to maintain both definitions.

It was also shown that for private goods, benefits are empirically measured as the area under the Marshallian (ordinary) demand curve even though the theoretically correct measure of benefits is the area under the compensated (Hicksian) demand curve. The market demand curve is used instead of the compensated demand curve because the market demand curve is observable. For public goods because of lack of market (market failure), consumers' preferences are not revealed in the market place. Economic factors that inhibit the perfect functioning of the market for water quality were also discussed. Alternative methods of discovering consumer valuation

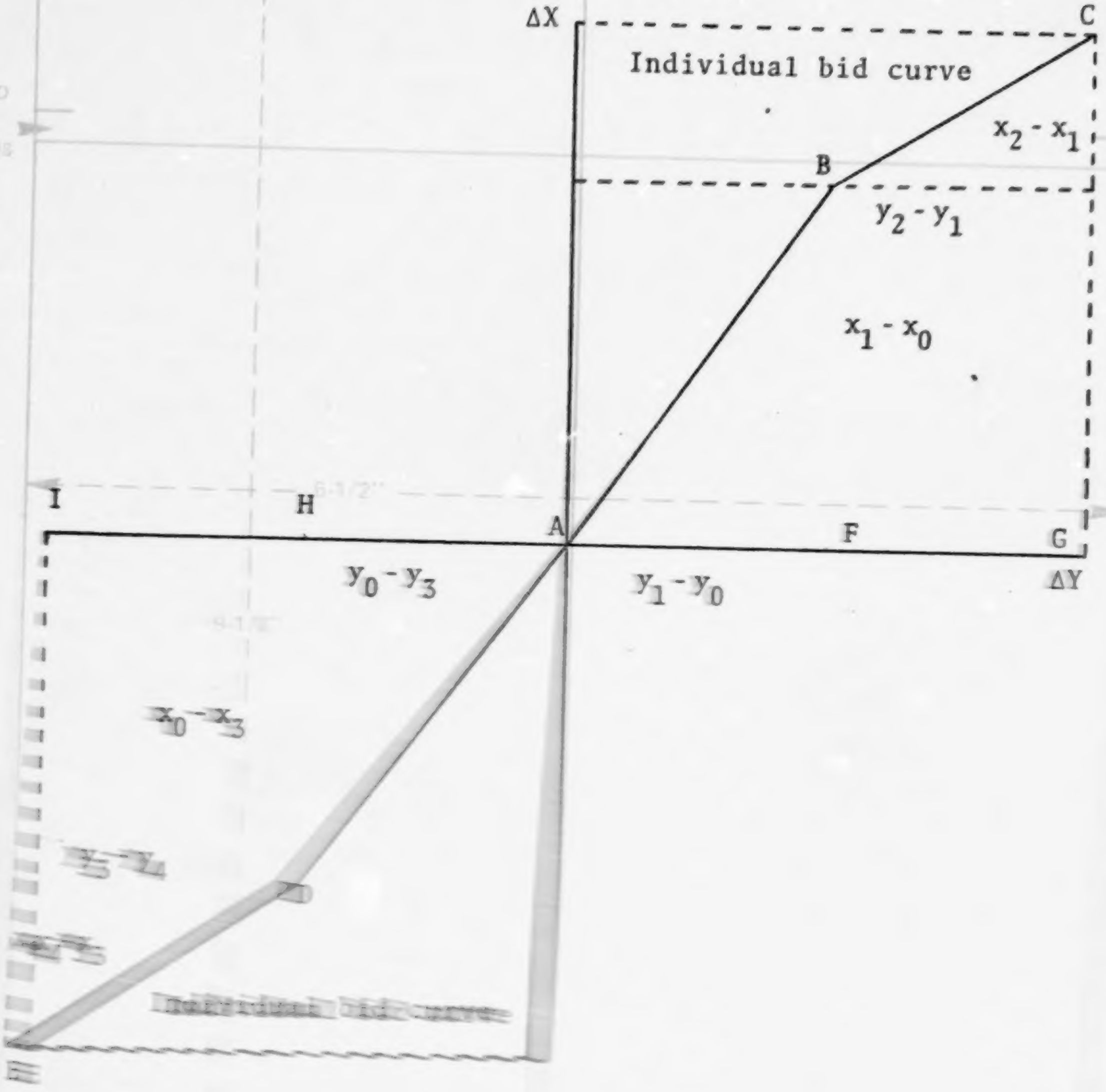
ΔX
C
Individual bid curve
$x_2 - x_1$
B
$y_2 - y_1$
$x_1 - x_0$
I
H
A
F
G
ΔY
$y_0 - y_3$
$y_1 - y_0$
$x_0 - x_3$
$y_3 - y_4$
D
Individual bid curve
E

Figure 7. Individual bid curve.

of the benefits of non-market goods (e.g., water quality) were discussed and analyzed both in principle and in practice. The discussion concluded that the direct approach of asking consumers their preferences about public goods is the preferred approach, despite some weaknesses. Finally, the concept of bidding curves was discussed to provide a theoretical justification for using the direct approach in the valuation of public goods (e.g., water quality).

SECTION 5

THE ANALYTICAL MODEL

This section develops a general analytical model for estimating benefits of water quality improvements in an irrigated river basin. The analytical model consists of a water quality submodel and an economic submodel. The water quality submodel rates the suitability of the river water for specified uses. The economic submodel attaches monetary value to water quality changes for each water use.

The discussion begins with background on the impact of pollutants carried by irrigation return flows to set the stage for presentation of the water quality submodel in its general form. Then, methods of determining overall water quality for specific water uses are discussed and compared. Finally, background discussion is provided to set the stage for the development and presentation of the conceptual economic submodel.

IMPACT OF POLLUTANTS CARRIED BY IRRIGATION RETURN FLOWS

Irrigated agriculture diverts a considerable amount of water for crop production. Some of the water diverted is lost in the process of being transported to farms because of canal seepage, evaporation, etc. Some of the irrigation water applied to fields percolates through the soil or runs off the field as surface flow. The portion of the diverted irrigation water that become irrigation return flows is a potential transport media for pollutants. Irrigation return flows may contain one or more of the following: sediments, nutrients, pesticides, organic materials, salts, and pathogens. These pollutants affect the quality of the receiving water.

Water quality has meaning only in connection with a specific water use since water is a multiple use resource. The emphasis on use is important because water that is suitable for one use may not be suitable for another. Individuals determine the suitability of a given body of water for their own uses based on their senses of smell, sight, and taste. However, according to the National Academy of Sciences (1973), a more precise way of measuring water quality is to consider its physical, chemical, biological, and aesthetic characteristics. This essentially makes water quality an n-dimensional vector in which measurements on each characteristic form an element of the vector. This is shown in Equation 5.1:

$$X = (X_1, X_2, X_3, \ldots, X_j, \ldots, X_n) \qquad 5.1$$

where X is the water quality vector and X_j is the magnitude of the j^{th} characteristic of water measured in appropriate units. Based on these physical, chemical, biological, and aesthetic characteristics, water quality data can be evaluated to derive water quality criteria for specifiic uses (National Academy of Sciences, 1973). Once water quality criteria are established for specific uses, they can be used as a yardstick for determining whether a certain body of water is suitable for a specific water use or not. Quantifying water quality in terms of its physical, chemical, biological, and aesthetic characteristics is useful because the changes in water quality will alter one or more of these characteristics. It also enables the scientist to focus upon those characteristics of water experiencing change and to determine the resulting water quality change.

Defining and measuring water quality helps in assessing the impact on receiving waters of pollutants carried by irrigation return flows. In Table 1, Column 1, is a list of water quality characteristics that are commonly measured. The rest of the content of Table 1 will be discussed later. Sediment and temperature are physical characteristics of water, while chemical characteristics include dissolved oxygen, pH, phosphorus, nitrogen, total dissolved salts, and pesticides. The precise impact of a particular pollutant upon water use is an empirical matter. Still, some indications can be given as to the magnitude of the problem and direction of effect upon uses (adverse, neutral, or positive) of a particular pollutant. The discussion below evaluates the impact of the major pollutants carried by return flows on major uses.

Sediment

Sediment is a significant water pollutant from agriculture (Task Committee of the American Society of Civil Engineers, 1977; U.S. Environmental Protection Agency, 1973). The amount of it that reaches streams is staggering. For example, it is estimated that 2 billion tonnes wash into streams per year in the U.S., of which more than 1 billion tonnes are contributed from croplands (Task Committee of the American Society of Civil Engineers, 1977). According to Nelson (1968), sediment removal from streams, reservoirs, and harbors costs $250,000,000 per year in the United States. Also, sediment often carries plant nutrients and certain pesticides while being transported by irrigation return flows.

Sediment and suspended materials adversely affect water quality for most uses. Irrigation water containing a considerable amount of sediment and suspended solids may lead to the deposition of films on leaf surfaces if sprinkler irrigation is used. According to the National Academy of Sciences (1973), the deposition of film reduces photosynthetic activity and retards plant growth. Deposition of sediment and other suspended solids on leafy vegetable crops may also affect their marketability.

The deposition of sediment in water conveyance systems reduces their capacity to carry and distribute water. Removal of sediment from canals, drains, and irrigation ditches is expensive. For example, Huszar and co-

Table 1. Water quality criteria for selected water quality characteristics and uses

Water quality characteristic	Unit	Water uses				
		Public water supply	Irrigation	Industry	Fish and aquatic life	Recreation
Ammonia	mg/l	0.5^{C} [a]	---	---	0.02^{E}	0.02^{E}
Nitrate	mg/l	$<10^{N}$	---	---	$0.30^{N,S,C}$	$0.30^{N,S,C}$
Nitrite	mg/l	$<1^{E}$	---	$<1^{E}$	0.02^{E}	0.02^{E}
Total phosphorus	mg/l	---	---	---	$<0.05^{E}$	0.05^{E}
Phosphate phosphorus	mg/l	---	---	---	$0.01^{N,C,S}$	$0.01^{N,C,S}$
Turbidity	JTU	1.0^{E}	---	250^{L}	$10\text{-}25^{L}$	$10\text{-}50^{T}$
Dissolved oxygen	mg/l	$4\text{-}7^{L}$	---	1-2	$>5^{E}$	$>5^{E}$
Total coliform bacteria	Organisms per 100 ml	$200^{N,E}$	200^{N}	200^{N}	200^{N}	200^{N}
Hydrogen ion concentration	pH	$5\text{-}9^{E}$	$6\text{-}9.5^{L}$	$6.0\text{-}9.5^{L}$	$6.5\text{-}9.0^{E}$	$6.5\text{-}9.0^{E}$
Conductivity	µmhos per cm at 25°C				$150\text{-}500^{N,C}$	$150\text{-}500^{N,C}$
Dissolved solids	mg/l	500^{T}	750^{N}	$100\text{-}1000^{L}$		
Suspended solids	mg/l		---		$20\text{-}80^{EU;N}$	$20\text{-}80^{EU,N}$
DDT	µg/l	$.002^{N}$		---	$.002^{N}$	$.002^{N}$
Temperature	°C	15.7^{CC}	---	---	15.7^{CC}	18.3^{CC}

[a] The capital letter superscripts refer to the following sources:

C: California State Water Quality Control Board, 1963, Water Quality Criteria, Sacramento.

E: U.S. Environmental Protection Agency, 1976, Water Quality Criteria (pre-publication copy), Washington, D.C.

N: National Academy of Sciences, Committee on Water Quality Criteria, 1973, Water Quality Criteria 1972, Washington, D.C.: U.S. Government Printing Office.

S: Sawyer, C. N., 1947, Fertilization of lakes by agricultural and urban drainage, Journal of the New England Water Works Association 61:109-127.

L: Liptak, B. G., editor, 1974, Environmental Engineers' Handbook, Vol. I. Water Pollution, Radnor, Pennsylvania: Chilton Books.

T: Todd, D. K., editor, 1970. The Water Encyclopedia, Port Washington, New York: Water Information Center.

EU: European Inland Fisheries Advisory Commission, Working Party on Water Quality Criteria for European Fresh Water Fish, 1965, Report on finely divided solids in inland fisheries, Air Water Pollution 9(3):151-168.

CC: California State Water Pollution Control Board, 1952, Sacramento.

authors (1978) report that $65,000 per year is spent in removing sediment from drains in the Sulphur Creek drainage of the lower Yakima River Basin and $50,000 per year in the Yakima-Tieton Irrigation District. Sediment and suspended solids can also cause undue wear on irrigation pumps and sprinkler nozzles.

Recreational and aesthetic water uses also may be adversely affected by the presence of sediment and suspended solids in surface waters. In general, their presence renders water aesthetically unpleasing due to reduced clarity. Suspended sediment and particles may absorb solar energy and lead to warmer surface temperature and lower oxygen transfer from air to water. This is particularly important in lakes and slow moving rivers.

Fishing and other aquatic life forms may also be adversely affected by sediment and suspended solids. Reduced light penetration decreases the ability of fish to find food. Buck (1956)) found that yield of fish per hectare declined from 180.9 kg to 32.8 kg as the sediment and suspended solids concentration increased from less than 25 mg/l to over 100 mg/l. If the dissolved oxygen level is reduced, fish and other aquatic organisms may be unable to survive. Deposition of sediment on river beds may cover fish eggs and aquatic life forms which serve directly or indirectly as food for fish (National Academy of Science, 1973).

Drinking water appearance and taste may also be affected adversely be sediment and suspended solids. According to Tracy, Camerena, and Wing (1966), sediment also reduces the effectiveness of chlorination by physically protecting microorganisms from direct contact with the disinfectant. Industrial water uses can also be affected by sediment and suspended solids. However, the water quality requirement of industrial uses is very diverse. Some industrial uses such as cooling can tolerate water with considerable amounts of supended sediment and solids. Other industrial water uses may have stringent quality requirements for sediment and suspended solids.

The loss of topsoil in the form of sediment has other economic costs. Topsoil loss leads to reduced productivity of croplands and increased application of fertilizers to compensate for decreased soil fertility.

Plant Nutrients

Irrigation return flow water also may transport plant nutrients such as nitrogen and phosphorus to streams. Fertilizers are well known sources of nitrates (NO_3) and the phosphates (PO_4) in return flows. However, they are not the only source of these nutrients.

The presence of nitrates in irrigation water may be considered an asset rather than a liability for crop growth, and nitrate concentrations high enough to adversely affect plants are rare (National Academy of Sciences, 1973). Similarly, the presence of phosphates in irrigation water is also considered an asset for plant growth. However, these same elements in irrigation return flows reaching ground or surface waters can cause great mischief.

Drinking water containing a high level of nitrates has been known to cause fatal poisoning of infants. Nitrate is reduced (converted) into nitrite by bacteria that grow in the infant's stomach. Nitrite absorbed into the blood stream converts hemoglobin into methemoglobinemia. The altered pigment fails to transport oxygen and the infant suffers from oxygen deprivation or suffocation. Methemoglobinemia is often called "the blue baby syndrome" because often the victims are infants less than 3 months old (Walton, 1951; National Academy of Sciences, 1973).

The presence of phosphorus and nitrate at higher concentration may create algae and other aquatic plant growths to produce discoloration and a bad taste in drinking waters (Dunne and Leopold, 1978). They may also increase drinking water treatment costs.

The addition of nitrates and phosphates into rivers and lakes used for recreation may adversely affect the quality of water for their use. Given the proper conditions, nitrates and phosphates can promote prolific algae and aquatic plant growths (Sawyer, 1947). Such algal growth can cause discoloration of the receiving water. Algae, upon their death and decay, rob the water of oxygen, causing possible fish and other aquatic animal kills (Dunne and Leopold, 1978).

Pesticides

Pesticides are chemicals (natural and synthetic) used to control or destroy plant life that reduce agricultural production (National Academy of Sciences, 1973). They are used for a wide variety of purposes and are often categorized according to their intended target. Four major categories of pesticides are important in agriculture. These are insecticides, fungicides, herbicides, and rodenticides. The majority of pesticides used extensively in agriculture are either insecticides or herbicides.

A large number of pesticides are not easily soluble in water but only in fatty substances. As a result, they attach themselves on suspended or sedimented materials in the process of being transported by irrigation return flows to receiving streams. No definitive data exist on the individual behavior and effect of pesticides (National Academy of Sciences, 1973). Thus, what follows is qualitative description based on limited scientific investigation on organchlorines, the most widely used family of insecticides.

People may absorb some pesticides into the fatty tissues of the body. The effect of pesticides being stored in fatty human tissues presently is not known. It is believed, however, that they cause symptoms of poisoning but differ in severity depending on the concentration of the pesticide in the nervous system (National Academy of Sceinces, 1973).

Water resources receiving pesticides may also adversely affect recreational, fishing and aquatic life uses. In receiving streams, the concentration of pesticides (organchlorines) are normally very low since they are not easily soluble in water. Most, but not all, pesticides travel attached to sediment and suspended solids. In streams, pesticides, because of their solubility in fatty substances, can be concentrated in aquatic plants. As the aquatic plants are eaten by fishes, the pesticide is dissolved in the stomach of the fish and stored within the fatty tissues of fish. The concentration of pesticides in the bodies of the larger animals that prey on zooplankton or smaller fish increases because the pesticide dissolves in fats rather than being excreted into water (Dunne and Leopold, 1978; National Academy of Sciences, 1973).

Organic Loads

Irrigation return flow water may also transport degradable organic farm wastes to receiving streams. Their source may be human or animal wastes. In many rural communities, it may not be economically feasible to install sewer system and waste treatment plants. It is believed that many of the septic tanks in which households in rural areas dispose of their wastes do not work properly because of bad design and poor siting (Dunne and Leopold, 1978). Most farm animal wastes are not treated at all and are easily picked up by rainfall runoff or irrigation water in the return flow process. As a result, some of the farm wastes end up in streams or lakes either through subsurface or surface flows.

The presence of organic wastes in significant amounts in streams adversely affects most water uses. It may be objectionable to most users because of possible bad odor, taste, and sight. Organic wastes increase the nutrient load of streams and dissolved oxygen consumption in the receiving water to break down organic wastes into stable end products requires a large amount of oxygen. This requirement reduces the dissolved oxygen content of the water and, hence, the quality of the water for most uses. Such wastes may also be a direct source of disease for humans or other animals.

Dissolved Salt Loads

Irrigation return flows may also transport dissolved salts such as sodium, calcium, magnesium, chlorides, sulfates, and bicarbonates from farms to receiving streams. In arid and semi-arid areas, a large portion of the irrigation water applied is evaporated or transpired by plants causing a two-fold or three-fold concentration of dissoved salts (Dunne and Leopold, 1978). A large proportion of the salt concentrated due to evapotranspiration of irrigation water is returned to the river. Repeated diverson of the stream water for irrigation may lead to severe salt concentration in the stream. Thorne and Peterson (1967) report that salinity, measured by the electrical conductivity of a solution, increased twentyfold when seven complete diversions of the Sevier River in Utah were made.

The salt content of irrigation water is important to farmers. High salt concentrations in the soil may depress plant growth and yield (Ayres, 1977; Christiansen et al., 1977). Salinity does not have the same effect on all plants. For example, asparagus, barley, date palm, and bermuda grass are considered salt tolerant crops while apples, strawberries, and green beans have low salt tolerance (U.S. Salinity Laboratory Staff, 1954; Bernstein, 1964).

Farmers are not the only losers from increased salt concentrations in receiving waters. The presence of high mineral salts, particularly sulphate and chloride, are associated with costly corrosion damage in water systems of public water supplies (National Academy of Sceinces, 1973). Mineralized waters also cause damage to household applicances and plumbing (Tihansky, 1973). In addition, Bruvold, Ongerth, and Dillehay (1969) reported that consumer preference of mineralized waters decreased in direct proportion to increased salinity.

Pathogens

The presence of pathogenic microorganisms such as bacteria and virus in irrigation return flows entering receiving waters pose possible health hazards. Pathogenic bacteria and virus may enter irrigation ditches from poorly treated rural human and animal wastes.

The presence of pathogenic microorganisms in streams severely reduces water quality and limits water use because of public health considerations. The National Academy of Sciences (1973) reports on a study by Smith and Woolsey in which swimming in river water having a median coliform bacterial density of 2,700 per 100 ml caused a statistically significant increase in illness among swimmers in the Ohio River.

STANDARDS, CRITERIA, AND CRITICAL LEVELS FOR WATER QUALITY CHARACTERISTICS

The National Academy of Sciences (1973) draws a distinction between water quality standards and water quality criteria. Water quality criteria refer to "the scientific data evaluated to derive recommendations for characteristics of water for specific uses." Water quality criteria are then used to recommend appropriate levels of the characteristics of water quality (physical, chemical, and biological) for each specific use, that is, to establish official water quality standards. Water quality standards are set with socio-economic considerations in addition to scientific knowledge about pollutants and water quality impacts.

Critical water quality levels do not have the official status of standards. No precise definition exists for them. However, it appears that they delineate the point at which any further increases in the level of the specific pollutant may severely restrict or halt water use. Even though the distinctions among standards, criteria, and critical levels are important, the ultimate goal of all three is to protect public health and enhance social well being by setting quality levels that maintain different water uses based on current scientific knowledge. Water quality criteria and standards may be changed as more evidence is gathered.

Aquatic scientists have studied and established acceptable levels for the various characteristics of water quality for specific water uses. Some of these water quality criteria have been made into water quality standards by governments and international agencies. For example, the U.S. Public

Health Service sets drinking water quality standards. The World Health Organization, an agency of the United Nations, also sets limits for the physical, chemical, and biological characteristics of drinking water. Most states in the U.S. also have their own water quality standards for all beneficial uses of water.

Since water is a multi-use resource, each water use must have its own standards. This is because some uses may be very strict (e.g., drinking water), while others may be lax (e.g., certain industrial cooling uses). Thus, the water quality standards must be use-specific.

Table 1 gave a summary of selected water quality standards for five major water uses. It should be noted that water quality standards do not exist for each and every water quality characteristic and use. Usually, water quality standards are set for water quality characteristics that adversely affect and interfere with water use. In other cases, aquatic scientists may not have enough knowledge to set water quality standards for some characteristics. That will change as more knowledge is gained. Thus, Table 1 may be viewed as a general guideline to water quality evaluation for different uses given the present state of scientific knowledge.

THE ANALYTICAL MODEL

The analytical model to be developed for estimating the benefits of river water quality improvements in an irrigated river basin consists of a water quality submodel and an economic submodel.

The Water Quality Submodel

The water quality submodel determines the overall quality of a given water body for specific water uses with respect to selected water quality characteristics. The model aggregates the effects of different water quality characteristics into an overall water quality rating for a specific use.

Assume that there are k water uses in an irrigated river basin and r reaches of the river. Let the water quality at reach r be depicted by a vector X with c components where X_j^r is the measured level of the j^{th} characteristic of water quality at reach r. This is shown in Equation 5.2. Assume further that the water quality standards are given, and let the water quality standard for the jth characteristic in use k be denoted by X_{jk}

$$X = (X_1^r, X_2^r, \ldots, X_j^r, \ldots, X_c^r) \tag{5.2}$$

Aquatic science provides the background to delineate the water quality characteristics that are relevant for each of the k specific water uses. Assume that only p of the c characteristics (where $p < c$) are important to the k^{th} use, where p is a positive integer. Thus, the k^{th} use depends on these p characteristics. Similarly, the characteristics that are relevant for all the other k-1 uses can be specified. Once the measured levels of a pollutant (that adversely affects some use) exceeds acceptable limits, then

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water users decrease their level of use. The level of water use may be severely inhibited and reach zero if the level of pollution is dramatically increased. Figure 8 shows that the water quality standard $\overline{X}_{jk}$, divides the levels of characteristic X_{jk} into tolerable ($X_{jk} < \overline{X}_{jk}$) and intolerable ($X_{jk} > \overline{X}_{jk}$) levels of water quality. This, however, does not mean that water containing tolerable levels of a pollutant is equally suitable for a given use. In fact, one would expect water with less pollutant in it to provide more utility to the user. Clearly, the satisfaction derived from using water with more and more units of a pollutant declines, even if the water quality is within tolerable limits. Thus, the depiction in Fig. 8 defies accepted expectations and a better way of depicting this phenomenon is needed.

A more realistic way of depicting the change in water quality for a specific use k due to additional levels of a specific pollutant is to subdivide the measured levels of characteristic X_j that is affected by the pollutant into more homogeneous subdivisions. This is shown in Fig. 9. These subdividisons can be labeled using descriptive terms such as perfect, very good, good, and poor. However, because of the arbitrary and imprecise use of the adverb very and adjectives perfect, good and poor, it is essential to define these terms more precisely so that the distinctions among these terms are clear to aquatic scientists and water users. A problem, however, with descriptive terms is that they are just words and cannot be changed without dubbing some additional descriptive terms in front of them.

To circumvent this problem of depicting variations within a given subdivision of water quality (e.g., good) without using an additional term, it is more precise and convenient to use numbers for delineating the subdivisions and also variations within subdivisions. For example, in this study the descriptive term very poor was assigned numbers between 0 and 30 while poor was assigned numbers ranging from 30 to 60. The term good was assigned numbers ranging from 60 to 85 while very good ranged from 86 to 99. Finally, the term perfect was assigned the number 100. Essentially, this approach is a grading system which allows for variations within a subdivision. This scheme is shown in Fig. 10. Note that L_1, L_2, L_3, and L_4 are boundaries for the various subdivisions of water quality with respect to X_j. All other things being equal, it is assumed that water users derive more satisfaction from a higher water quality than a lower one.

A further improvement was to develop a continuous function rather than the discrete step function shown in Fig. 10. The exact functional relationship between water quality characteristic X_j and water quality rating for use k with respect to X_j is an empirical question. However, Equation 5.3 gives the general case.

$$I^r_{kj} = f(X_j) \qquad (5.3)$$

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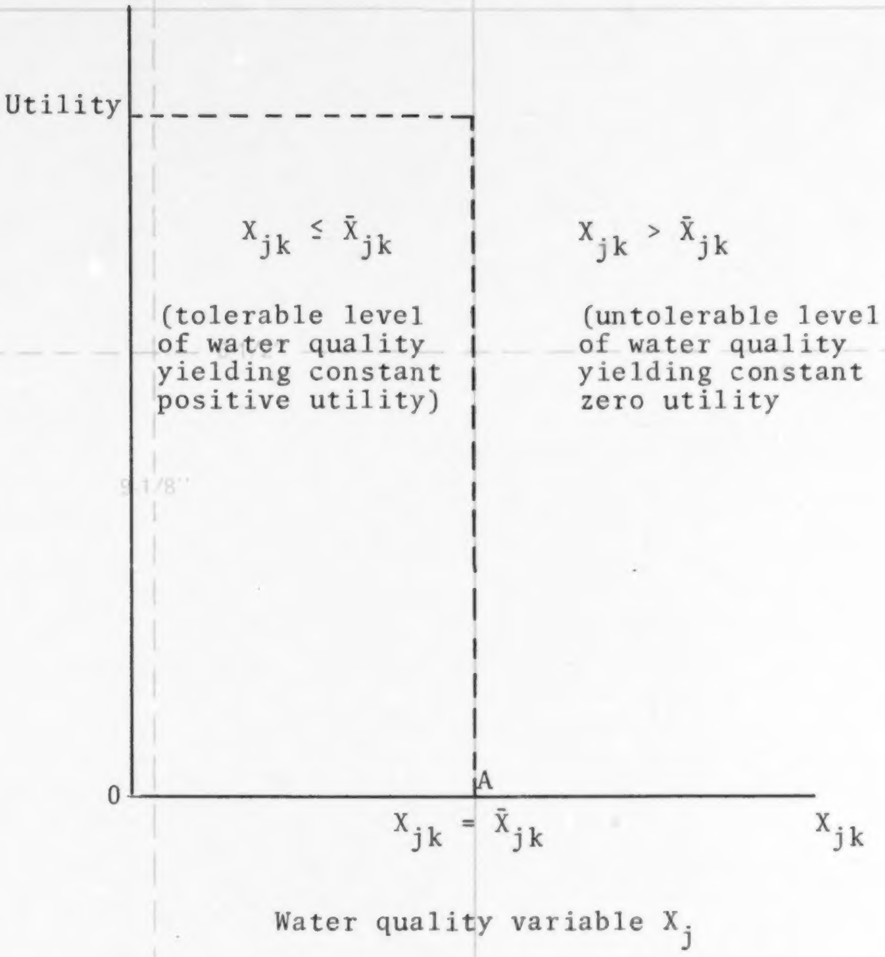

Figure 8. A naive interpretation of water quality standards for a water quality parameter X_j in use k.

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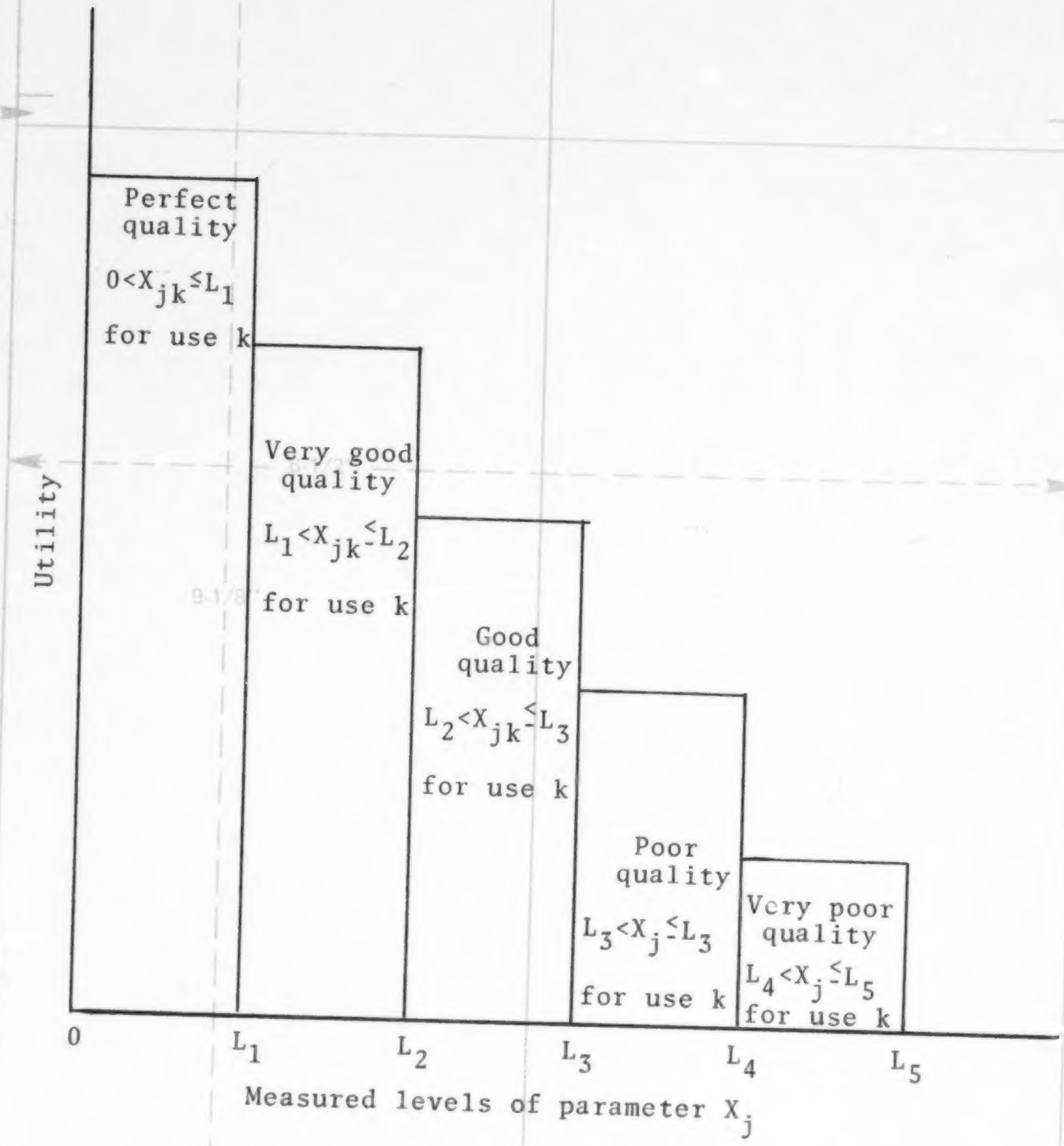

Figure 9. A descriptive approach to interpreting water quality standards for water quality parameter X_j in use k.

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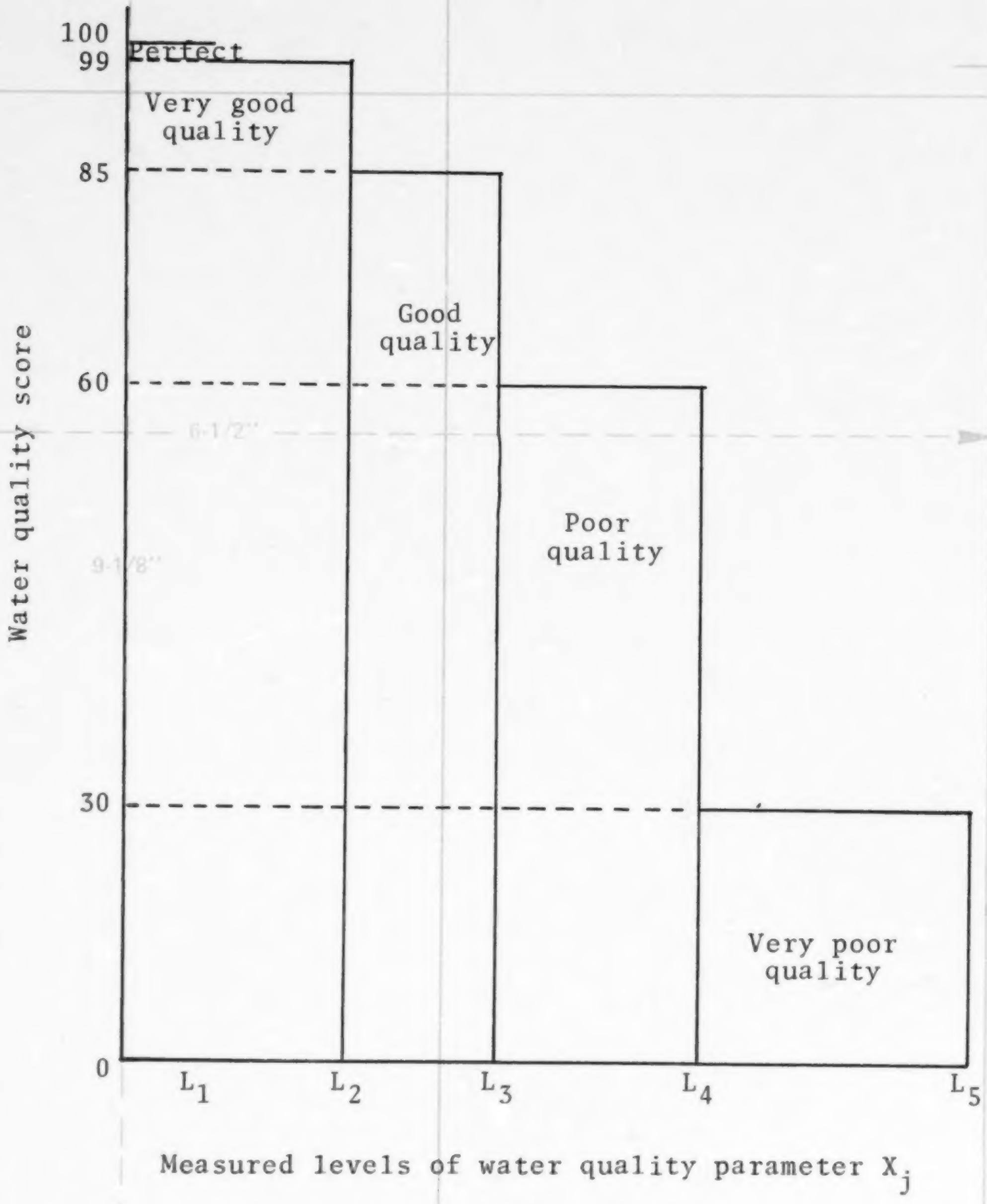

Figure 10. A scoring approach to water quality rating with respect to parameter X_j in use k.

where I^r_{kj} is the water quality index in river reach r for use k with respect to water characteristic X_j and f is an unspecified functional form. In this study, a function such as $f(X_j)$ which assigns quality index for a specific use k with respect to X_j will be referred to as a water quality rating function or a water quality index function. Figure 11 shows a linear water quality index for use k with respect to X_j. In practice, maximum and minimum values are specified for I^r_{kj}. For water quality, 100 is the highest value and zero is the minimum value of I^r_{kj}. It should be noted that Figs. 8 through 11 assume that characteristic X_j is an undesirable characteristic such as increased levels of sediment and turbidity. This need not always be the case. For example, an increased level of stream flow or dissolved oxygen is desirable. Hence, for stream flow and dissolved oxygen I^r_{kj} increases with increased levels of these two water quality parameters.

The Water Quality Index

Having specified the water quality rating functions for each of the k water uses and c water quality characteristics, the next step is to determine the aggregate water quality index for use k with respect to all the characteristics that influence use k. That is, given the water quality indices (I^r_{kj} in Equation 5.3) for each of the characteristics X_j for water use k, it is necessary to determine the aggregate water quality index for use k. It is clear that the aggregate water quality index for water use k depends on the relevant characteristics of water quality. This is given by Equation 5.4.

$$Q^r_k = g[f(X^r_j)] \qquad (5.4)$$

where Q^r_k is the aggregate water quality index in reach r for use k with respect to selected water quality characteristics and g represents a general aggregation form. Notice that $f(X^r_j)$ comes from Equation 5.3. In general, the maximum and minimum values that Q^r_k assumes are specified as 100 and zero respectively.

Several approaches are available for combining the water quality indices $f(X^r_j)$ given in Equation 5.3 into an overall water quality index given by Equation 5.4. Here, only three approaches will be reviewed. These are the additive and multiplicative forms, maximum operator, and minimum operator. For additional aggregation forms and detailed explanations, the interested reader should consult Ott (1978).

The additive aggregation forms derive the aggregate water quality index Q^r_k) by adding the water quality indices (I_{kj}) for each characteristic j. This is shown in Equation 5.5.

$$Q^r_k = \sum_{j=1}^{c} I^r_{kj} \qquad 5.5$$

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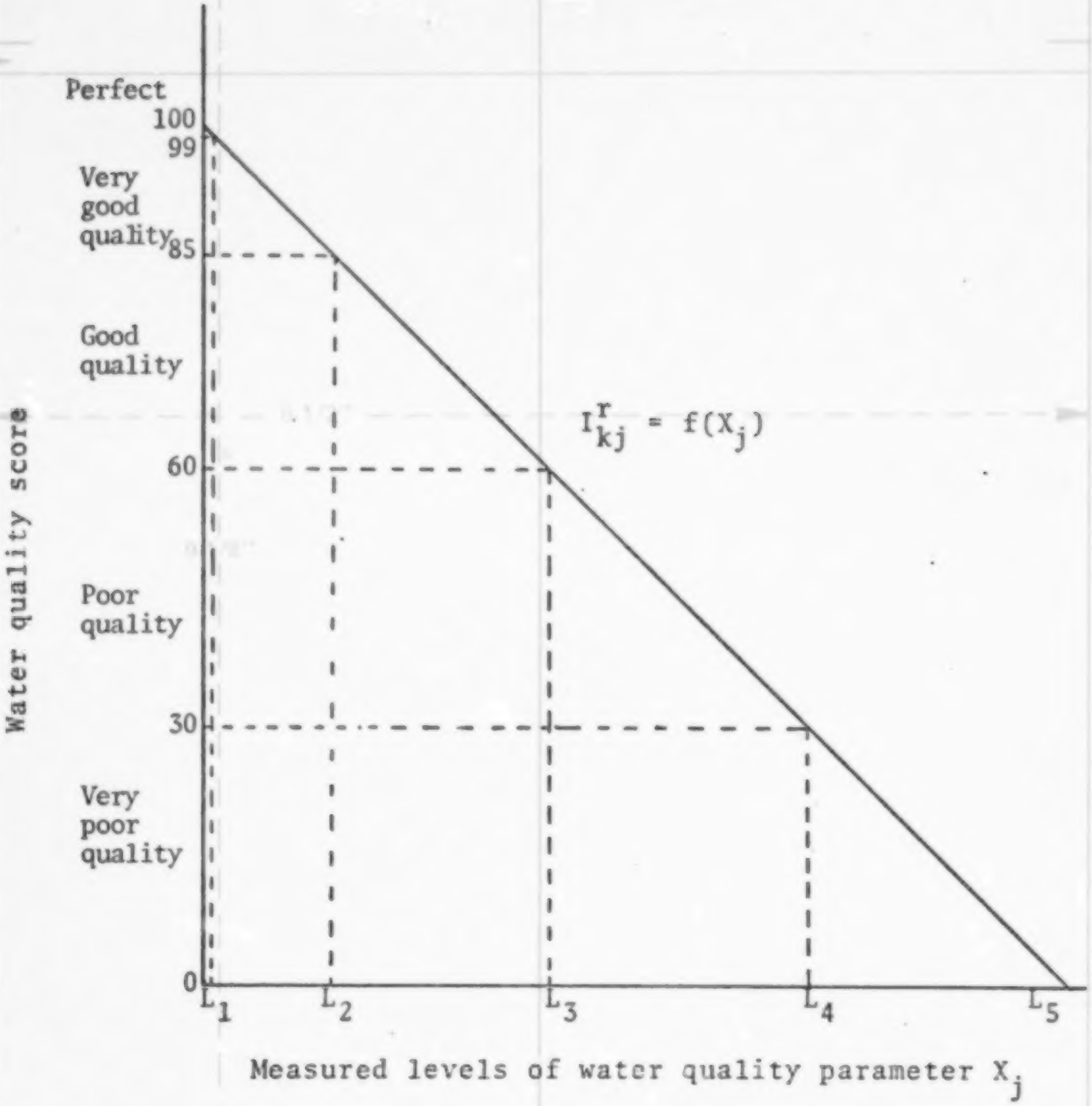

Figure 11. A functional approach to water quality rating with respect to water quality parameter X_j in use k.

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In Equation 5.5, the limits on values for Q_k^r and I_{kj}^r would not be the same.

Equation 5.5 can be forced to provide a water quality index (Q_k^r within the range 0 to 100. This can be done by assigning a weight to each water quality score (I_{kj}^r) such that the sum of the weights is unity. The new aggregation form called the weighted linear sum (Ott, 1978) has the general form shown in Equation 5.6.

(5.6) $$Q_k^r = \sum_{j=1}^{c} w_j I_{kj}^r$$

where w_j is the weight attached to the jth water quality score for characteristic X_j and $\sum_{i=1}^{c} w_j = 1$.

The major problem with this form of overall quality measurement is that it fails to recognize the limiting effect of a particular quality characteristic on the intended water use. For example, it would be possible for all but one characteristic (say, dissolved oxygen) to be within a tolerable range for a fishery and still have no fish production. In Equation 5.6, a given water quality score (I_{kj}^r) may have a very low score, but the overall water quality index (Q_k^r) fails to reflect this fact. The situation when the overall water quality index (Q_k^r) exaggerates actual water quality is called eclipsing by Ott (1978).

The multiplicative form or weighted product form helps to circumvent the eclipsing problem encountered by the weighted linear aggregation form (Equation 5.6). The multiplicative form is shown in Equation 5.7.

(5.7) $$Q_k^r = \prod_{j=1}^{c} I_{kj}^{w_j}$$

The weighted product form (Equation 5.7) removes the severe eclipsing problem introduced by the weighted linear form (Equation 5.6) for very poor water quality score (e.g., $I_{kj}^r = 0$). If any I_{kj}^r is zero than Q_k^r in Equation 5.7 becomes zero. The weighted product form (Equation 5.7) is biased towards the lowest water quality scores and may underestimate the overall water quality. Ott (1978) also describes an additional problem inherent in the use of the weighted product form (Equation 5.8). This problem concerns the nonlinearity that is introduced when the weights (w_j) attached to each water quality score (I_{kj}^r) are very small. This is because the weighted product form (Equation 5.7) tends to transform each water quality index $I_{kj}^r = f(X_j)$ given by Equation 5.3 by raising it to the power w_j. The transformation may cause distortion by changing the value of I_{kj}^r when the value of w_j is very small.

To correct for the deficiencies of the weighted linear form (Equation 5.6) and weighted product form (Equation 5.7), it has been suggested that the ideal water quality index be used. The ideal water quality index is given in Equation 5.8.

$$Q_k^r = \frac{\sum_{i=1}^{c} w_j I_{kj} + \prod_{j=1}^{c} I_{kj}^{w_j}}{2} \tag{5.8}$$

It is not clear if the ideal water quality index completely overcomes the problems that plague the weighted linear form and weighted product form that comprise it.

Another option for determining the overall water quality index (Q_k^r) in Equation 5.4 is to use the maximum operator rule. Equation 5.9 gives the general form of the maximum operator.

$$Q_k^r = \max(I_{kj}^r) \tag{5.9}$$

In the maximum operator (Equation 5.9), the aggregate water quality index becomes the highest of the water quality indices (I_{kj}^r). The maximum operator (Equation 5.9) is ideal for applications in which the water quality index should determine the water quality characteristic that is least constraining a given water use. Such information, however, may be useful but it says nothing about pollutants that may be restricting some water uses. It should be noted as a matter of historical fact that the maximum operator was developed for use in determining the Pollutant Standard Index (PSI) by Thom and Ott (1976). The PSI is an increasing scale form, that is, it increases with increasing pollution. However, water quality indexes are normally of decreasing scale form; that is, the index value decreases with increasing pollution. The maximum operator avoids both the problems of eclipsing pollution and exaggerating pollution. However, the capacity to recognize differences in the various water quality scores (I_{kj}^r) is not available. Thus, the maximum operator is not a suitable aggregation form when considerations of water quality scores other than the maximum water quality score (I_{kj}^r) are important.

A final aggregation form to be discussed is the minimum operator rule. The general form of the minimum rule is shown in Equation 4.10.

$$Q_k^r = \min\ (I_{kj}^r) \tag{5.10}$$

The minimum operator rule selects the water quality index I_{lk}^r with the smallest I_{kj}^r value. In other words, the overall water quality Q_k^r is determined by the water quality characteristic that most limits use k. Like the maximum rule (Equation 5.9) the minimum rule avoids problems of eclipsing, that is, exaggerating water quality. The minimum rule puts all the emphasis on the pollutant that is most limiting. The minimum rule also suffers from the same problem affecting the maximum rule--it ignores the other water quality scores (I_{kj}^r) and attaches zero weights to characteristics that are not limiting to use k. This is the functional form chosen for use in this analysis.

Summary

The general form of the water quality submodel specified is as follows:

(5.11) $$X = (X_1, X_2, \ldots, X_j, \ldots, X_c)$$

(5.12) $$X_{jk} \gtreqless \overline{X}_{jk}$$

(5.13) $$I^r_{kj} = f(X_j)$$

(5.14) $$Q^r_k = \Phi[f(X_j)]$$

is a minimum if Equation 5.10 applies and a maximum if Equation 5.9 applies.

(5.15) $$\Phi = \sum_{j=1}^{c} w_j I_{kj} \text{ for } \sum_{j=1}^{c} w_j \qquad \text{if Equation 5.6 applies.}$$

$$\prod_{j=1}^{c} (I^r_{kj})^{w_j} \qquad \text{if Equation 5.7 applies.}$$

$$\frac{\sum_{j=1}^{c} w_j I^r_{kj} + \prod_{j=1}^{c} (I^r_{kj})^{w_j}}{2} \qquad \text{if Equation 5.8 applies}$$

(5.16) $$H_1 \leq I^r_{kj} \leq H_2$$

(5.17) $$H_3 \leq Q^r_{kj} \leq H_4$$

Equations 5.11 through 5.17 comprise the water quality submodel. Equation 4.11 describes the water quality variables that have been chosen for analysis. Equation 5.12 determines whether the actual measured value of a water quality paramenter X_j in use k is greater than, less than, or equal to the water quality standard set for that parameter X_j in use k.

Equation 5.13 describes the relationship between water quality index (I^r_{kj}) and a water quality parameter X_j. Equation 5.14 determines the aggregate water quality index for water use type k in river reach r based on the c quality parameters chosen for analysis. Equation 5.15 provides five different forms which Φ (in Equation 5.14) can assume. In any given empirical study, only one of the five forms of Φ would likely be used. The choice of which form of Φ to use should be based on knowledge of the strengths and weaknesses of the various forms. In Equation 5.15, w_j refers to the weight attached to the water quality parameter X_j. Finally, Equations 5.16 and 5.17 define the range of values which I^r_{kj} and Q^r_{kj} can assume. In Equations 5.16 and 5.17, H_1, H_2, H_3, and H_4 are numerical constraints.

THE ECONOMIC SUBMODEL

The water quality submodel determines water quality ratings due to changes in the physical, chemical, and biological characteristics of water. These water quality ratings become data for the economic submodel in the determination of the value of water quality changes. The economic submodel provides a theoretical mechanism to measure the benefits individuals derive from water quality change. It also gives a theoretical mechanism for empirically estimating the economic value of river water quality changes in an irrigated river basin.

Background

The theory of consumer choice is fundamental to the valuation of an economic commodity such as river water quality improvements. Traditional consumer theory (for example, see Samuelson, 1947; Henderson and Quandt, 1971; Intriligator, 1971; Hicks, 1946, 1956) presents the consumer as a passive maximizer of utility (u) from the purchase of commodities (y_1, y_2, ..., y_r) with given market prices (P_1, P_2, ..., P_r) subject to an income (I) constraint. Stated formally, the consumer seeks to maximize utility (u)

$$u = u(y_1, y_2, y_i, \ldots, y_r) \tag{5.18}$$

subject to

$$\sum_{i=1}^{n} P_i Y_i \leq I \tag{5.19}$$

$$y_i \geq 0$$

Traditional consumer theory assumes that goods and services are consumed to provide utility directly to the consumer. It also maintains that goods and services (y_1, y_2, ..., y_n) are the objects of choice; that is, consumers have preferences for goods and services.

Traditional consumer theory is deficient in at least three major aspects. First, it ignores the characteristics (properties or attributes) that make goods desirable to a consumer and treats goods as one-dimensional entities. Second, traditional consumer theory diminishes the role of the consumption process in creating utility and gives the impression that utility is automatically obtainable by mere acquisition of goods and services by a consumer. The theory ignores the fact that in real life, one needs to combine goods, time, and skill to derive utility from a market good. Recreationists do not derive utility from clean water. They derive utility from the process of using the clean water along with time spent in recreational activities. Third, traditional consumer theory treats different quality levels of the same good as different goods. There is no metric or scale to determine the "closeness" of different goods (Leland, 1977) and no distinction is made between entirely different goods, for example, polluted water and bread, on the one hand, and differentiated products, say polluted water and clean water, on the other hand. A reformulation of the traditional consumer theory is essential to enhance its usefulness in the valuation of economic commodities.

Lancaster (1966, 1979) developed a new theory of consumer choice known as the characteristic approach. The essential feature of his approach is that it considers goods as bundles of characteristics. It also assumes that individuals' preferences for goods are actually preferences for the collections of characteristics which goods possess. The characteristic approach further assumes that the characteristics which goods possess are objective and finite. The demand for goods is derived demand and indirect, and depends on preferences for characteristics possessed by the goods. For additional information about preferences and the utility function in traditional consumer theory refer to Intriligator (1971).

Contrary to traditional consumer theory which maintains that the objects of consumer choice are goods and services, the reformulated consumer theory (Lancaster, 1966, Becker, 1965; Stigler and Becker, 1977) assumes that the objects of consumer choice are consumption activities. Stated formally, the consumer seeks to maximize

$$u = (A_1, A_2, \ldots, A_n) \quad (5.20)$$

with

$$A_i = g_i(F_{i1}, F_{i2}, \ldots, F_{ip}, t_{i1}, t_{i2}, \ldots, t_{in}) \quad (5.21)$$

where A_i represents consumption activity i, g_i is the production function for activity i, F_{ip} is the quantity of the p^{th} characteristic of market goods $y_1, y_2, \ldots, y_n$ that is used in the production of activity i, and t_{in} is the i^{th} person's own time input into the production of the i^{th} consumption activity.

The reformulated theory seeks to maximize utility (u) subject to income and time constraints. This approach in which basic activities are the objects of choice has advantages over traditional consumer theory. It recognizes that utility is created in the process of using a good, not just from the possession of a good. In addition, time and skill also play major roles in the derivation of utility from goods. An example is water recreation. First, an individual needs to transport himself to the river or lake, where, depending on the desired water recreational activity, he combines market goods (like swimming suits, skis, boats, rafts, fishing tackle, etc.), his own skill and training, his own time, and the environmental resource (water) to create recreational activities (like fishing, swimming, boating, rafting, water skiing, etc.) that yield satisfaction. The reformulated consumer theory has intuitive appeal. It is particularly well suited for studying environmental economics problems in which individuals combine a significantly large input of time and a negligible input of other market goods.

Cicchetti and Smith (1976) selected Lancaster's characteristics in their study of congestion costs in wilderness areas. The traditional theory of consumer choice, it should be noted, was developed for priced market goods. Environmental resources are not normally priced. Lancaster (1979) indicated that his characteristic approach accords with common sense and, thus, is easy to understand. It seems the reformulated theory will play a major role in the valuation of environmental resources.

Developing the Economic Submodel

The economic submodel provides the means for attaching monetary values to water quality change. It supplies a framework to derive the values that different water users attach to water quality changes.

Assume that there are k water uses and r river reaches in the irrigated river basin. That is,

$$S = (S_1^r, S_2^r, \ldots, S_k^r) \qquad (5.22)$$

where S is a vector showing the flow of services $S_1^r, S_2^r, \ldots, S_k^r$ from the river in river reach r.

Let the water quality at reach r be depicted by a vector X with c components as in Equation 5.2. The level of water use S_k^r in Equation 5.22 depends on the measured characteristics of water. However, all c water quality characteristics are not equally important to all uses. Some water uses may not be affected in any way by certain water quality characteristics. Thus, even though there are c quantitatively measurable characteristics of water quality in reach r, only a subset of them might be important for each use.

Water user preferences are stated in terms of water quality characteristics and other goods. Let the characteristics of other goods in the consumer's basket be represented by the vector d. That is,

$$D = (D_1, D_2, \ldots, D_n) \qquad (5.23)$$

Individual water user's utility (u_{ik}) is related to the objective characteristics of water and other goods. This is stated formally in Equation 5.24.

$$U_{ik} = u_{ik}(X_1^r, X_2^r, \ldots, X_i^r, \ldots, X_c^r, D_1, D_2, \ldots, D_n) \qquad (5.24)$$

The objective characteristics of water quality (X_j) are variables that only the aquatic scientist can measure and evaluate. The individual water user, however, depends on his own senses of sight, smell, and taste to evaluate water quality. Thus, to the individual water user, characteristics that are distinct to the sense of sight, smell, and taste are important in determining water quality. However, other relevant characteristics that are not detectable and may still endanger the health and welfare of the individual may be overlooked if only sensory organs are used as determinants of water quality. Clearly, organoleptic observations are no match for the sophisticated laboratory techniques that modern science has developed for measuring these physical, chemical, and biological characteristics of substances in water.

The objective measures include all of the characteristics that are considered by the water user plus other characteristics that the user cannot detect but may still affect his well being. Individuals may incorporate characteristics that their limited faculties (senses) fail to detect if information on these characteristics is available. The level of pollutants may be posted by a stream to allow individuals to decide whether to use the water. The problem with this approach is that each water user must be conversant with the scientific literature. One possible solution to the problem is for the aquatic scientist to construct a grading system or a water quality index that consists of all relevant water quality characteristics and define the scores in language that the average water user can understand. Given such a system, individual utility depends on the characteristics of water (Equation 5.24). Individual utility also depends on the water quality index (Q_k^r) which in turn depends on water quality characteristics. Hence, individual utility (u_{ik}) can be written as in Equation 5.25. As usual, it is assumed that the marginal utility of Q_k and D are positive. In other words, each good is desirable. Note that in Equation 4.25 increases in Q_k are viewed as increases in water quality.

$$u_{ik} = f(Q_k^r, D) \tag{5.25}$$

The i^{th} individual's perception of water quality (Q_{ki}^r) and the objectively measured aggregate water quality index (Q_k^r) approximate each other as more information is made available to the water user. This is shown in Equation 5.26. Ideally, one would like Q_{ki} and Q_k to be identical.

$$Q_k^r = h(Q_{ki}^r) \tag{5.26}$$

Value of Water Quality Change

Water quality changes may alter the suitability of water for different uses. This may result in changes in the utility derived from water use by different water users. The question is, how does one measure the economic value of water quality changes, i.e., how does one put monetary value on changes in individual and collective welfare changes because of water quality changes?

Freeman (1972) argued that the assignment of property rights to common property resource services, the acceptability of the existing distribution of income,and market prices should be determined before the valuation of the common property resource services can take place. The rights to common property resource services determines the appropriate conceptual foundation for measuring benefits. The attitude toward income distribution determines whether measures of benefits inferred from observed market-oriented behavior (e.g., shadow prices) are acceptable. Freeman (1972), p. 248 says, "If the present distribution of income is judged to be not acceptable, the benefit and cost estimates derived from existing techniques will, in principle, be wrong."

Depending upon the assignment of ownership right to the common property resource services, the appropriate benefits measure of water quality improvements are either the willingness to pay of the users for the services or the required compensation for the loss of the new services. One should be aware of the implication of adopting either the willingness to pay measure or the required compensation measure in water pollution abatement. Use of the willingness to pay measure implies acceptance of the prior assignment of property rights to the river to those who are using it for waste disposal and degrading water quality. Use of the required compensation measure of benefits implies that property rights reside in that segment of the public desiring high quality water, and the benefits of abatement are what these people would require in compensation for their degraded water. The economic submodel is developed using both the willingness to pay measure and the required compensation measure of benefits.

Suppose the consumer was initially at A on indifference curve IC_0 in Fig. 12, consuming other goods D_0 and water quality level Q_{k0}. In Fig. 12, let D be measured in terms of money. Hence, the price of D is one. Now, assume that water quality is to be changed from Q_{k0} to Q_{k1}. All other things remaining the same, this moves the individual from A to B momentarily. The move from Q_{k0} to Q_{k1} puts the consumer on a higher indifference curve at B (not shown in Fig. 12). To the individual, the value of the water quality change in terms of the other commodity (D) is BC or D_1D_0. Hence, if the water quality is changed from Q_{k0} to Q_{k1}, BC = D_0D_1 is the maximum amount that the consumer is willing to pay and still be as well off as he was at A, prior to the water quality change. After the change, if the consumer paid his maximum willingness to pay (BC) he would be at C in Fig. 12. Thus, one can visualize a series of water quality changes and the corresponding willingness to pay figures in terms of D (money) keeping the consumer on his initial indifference curve IC_0.

Figure 13 shows the water quality changes and corresponding willingness to pay taken from Fig. 12. Note that in Fig. 13 BC is the willingness to pay in terms of D corresponding to quality change from Q_{k0} to Q_{k1} and HI is the willingness to pay corresponding to quality changes from Q_{k3} to Q_{k4}. In Fig. 13, ACEQI is the individual marginal willingness to pay curve for water quality improvements in terms of D.

The diagram in Fig. 12 can also be used to derive required compensation when water quality is reduced. Suppose the water quality is to be reduced from Q_{k0} to Q_{k5}. This puts the consumer on a lower indifference curve (not shown) passing through J in Fig. 12. The consumer would not voluntarily agree to a quality deterioration unless he is compensated for it. A rational consumer would ask a minimum compensation of MJ = D_5-D_0 in fig. 12. A measure of required compensation figures can be derived as the water quality is reduced by small amounts, keeping the consumer on his initial indifference curve IC_0 in Fig. 12.

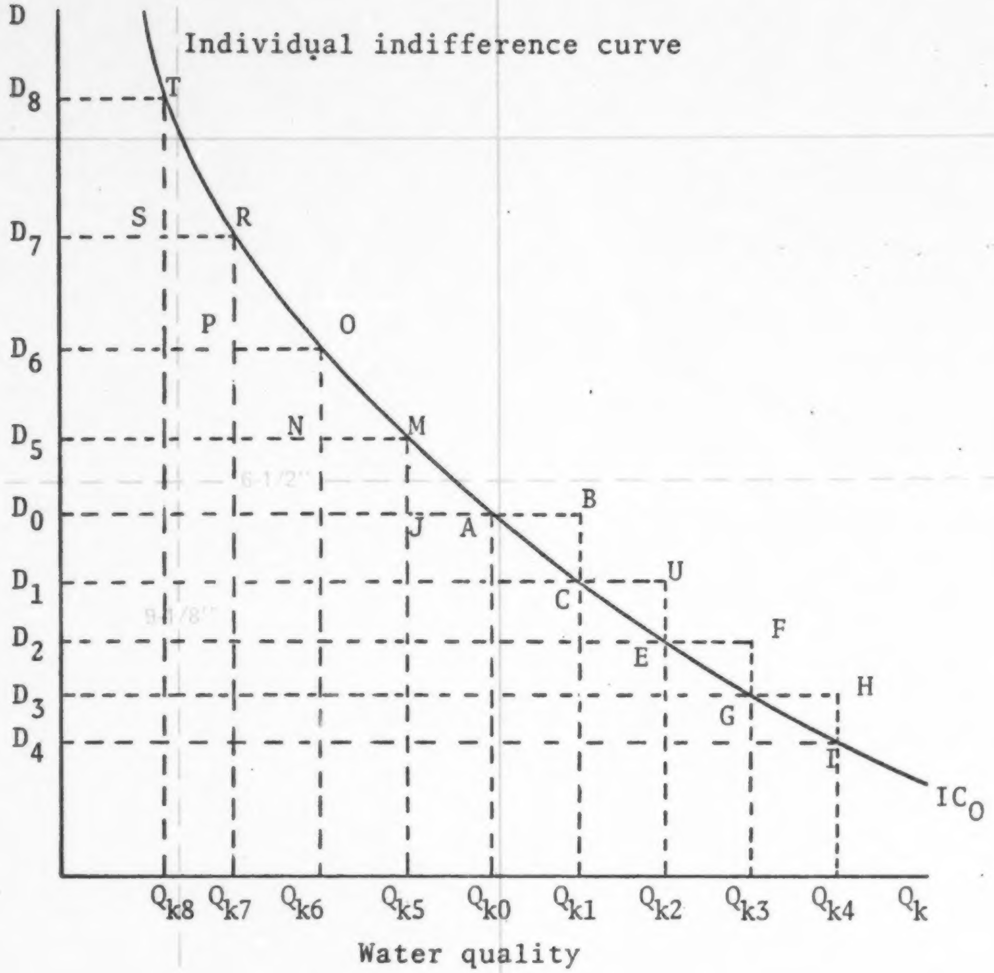

Figure 12. Individual indifference map for water quality (Q_k) and a composite good (D).

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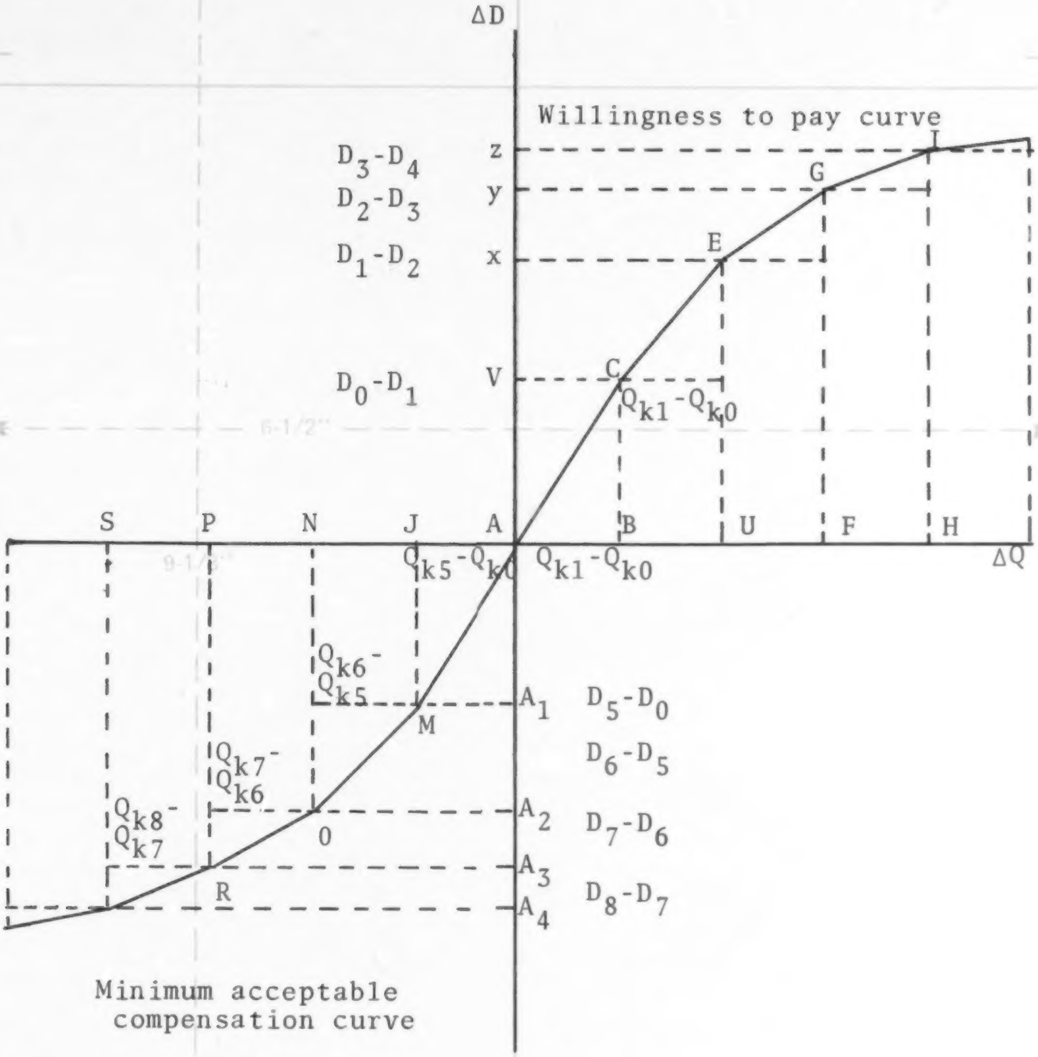
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x
D$_0$-D$_1$
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I
G
E
C
Q$_{k1}$-Q$_{k0}$
S
P
N
J
A
B
U
F
H
ΔQ
Q$_{k5}$-Q$_{k0}$
Q$_{k1}$-Q$_{k0}$
Q$_{k6}$-Q$_{k5}$
A$_1$
D$_5$-D$_0$
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D$_6$-D$_5$
Q$_{k7}$-Q$_{k6}$
Q$_{k8}$-Q$_{k7}$
A$_2$
D$_7$-D$_6$
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A$_4$
D$_8$-D$_7$
Minimum acceptable compensation curve

Figure 13. Individual willingness to pay and minimum acceptable compensation curves for changes in water quality.

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Figure 13 shows the water quality reductions and corresponding required compensation figures when the consumer is kept on his initial utility level IC_0. For example, D_5-D_0 is the compensation required corresponding to water quality reduction from Q_{k0} to Q_{k5} and D_6-D_5 corresponds to water quality reduction Q_{k5} to Q_{k6} in Fig. 12. In Fig. 13, AMORT represents the marginal minimum required compensation curve derived from Fig. 12.

Figure 13 is what Bradford (1970) called an individual bid curve. Individual bid curves depict the amount an individual is prepared to bid directly for small changes in water quality. An important observation that Bradford made was to view the individual bid curve in Fig. 13 as an indiffernce curve passing through point A, suitably re-oriented to fit new axes. Hence, the marginal willingness to pay curve (ACEGI) in Fig. 13 is essentially the same as Bradford's bid curve. The slope of the individual bid curve or willingness to pay curve in Fig. 13 is simply the individual's marginal rate of substitution of money (D) for water quality (Q_k) in use k, (MRS_{D,Q_k}). The MRS_{D,Q_k} shows how much the individual water user is prepared pay to obtain a small change in water quality. This is shown in Equation 5.27.

$$MRS_{D,Q_k} = -\frac{\Delta D}{\Delta Q_k} \qquad (5.27)$$

The willingness to pay function or bid curve as derived in Fig. 13 corresponds to a compensated demand function or a Hicksian demand function. This is because alternative water quality and other good combinations were determined by holding the individual's utility constant.

It is now clear that willingness to pay and required compensation both depend on water quality (Q_k) and other relevant variables (R). These relationships are given in Equations 5.28 and 5.29. The other relevant variables may include income, educational level, and attitude towards water quality. This study concentrates on the relationships that exist between P_{ik} and Q_k, and C_{ik} and Q_k.

$$P_{ik} = f(Q_k, R) \qquad (5.28)$$

$$C_{ik} = g(Q_k, R) \qquad (5.29)$$

where P_{ik} and C_{ik} are the i^{th} individual's willingness to pay and required compensation for water quality level Q_k in use k, respectively, and f and g are unspecified functional forms.

Aggregation of Benefits

The discussion has so far concentrated on obtaining an individual valuation of water quality change. However, to estimate benefits it is necessary to know the population affected by the change. The aggregate benefits for water quality changes in use k are obtained by vertically summing the individual willingness to pay curves (ACEG and others like it) in Fig. 13. The algebraic expression is given by Equation 5.30.

$$B_k = \sum_{i=1}^{N} \Delta P_{ik} \qquad (5.30)$$

where B_k is the aggregate benefit accruing to water use type k and ΔP_{ik} is the marginal willingness to pay for improvements in water quality. Equation 5.30 assumes that there are N individual beneficiaries from water use type k.

The aggregate social benefit from all M water uses and N users in each water use type is given by Equation 5.31.

$$B = \sum_{k=1}^{M} \sum_{i=1}^{N} \Delta P_{ik} \qquad (5.31)$$

Similarly, the benefits foregone from water quality deteriorations are the total amounts of money that individuals demand in compensation, without being any worse off than they were prior to the quality changes. The aggregate minimum acceptable compensation C for all water uses due to water quality reduction when there are N persons in each use type is given by Equation 5.32).

$$C = \sum_{k=1}^{M} \sum_{i=1}^{N} \Delta C_{ik} \qquad (5.32)$$

SECTION 6

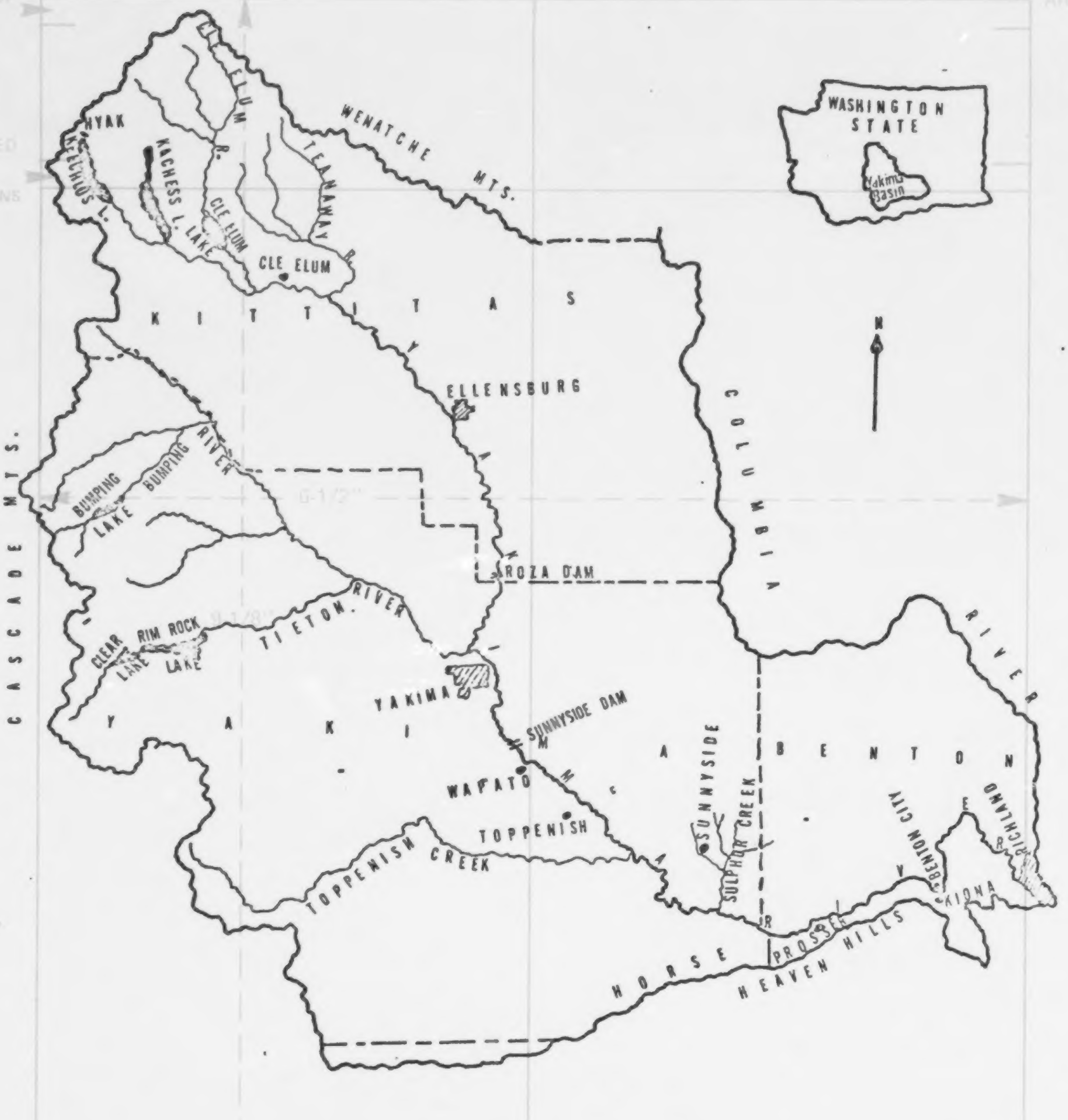
THE EMPIRICAL MODEL

This section develops an analytical model to measure pollution abatement benefits for application to a case study in the Yakima River Basin of Washington state. The material in this section is presented in three major parts. The first part provides background information on the study area and addresses water quality problems and their sources in the Yakima River Basin. Next, the empirical water quality submodel is explicitly derived for and applied to selected water uses in the Yakima River Basin. Finally, the third part derives the empirical economic submodel for selected water uses in the Yakima River Basin.

THE STUDY AREA

The Yakima Basin covers a total area of about 15,800 square kilometers (6,100 square miles) located in south-central Washington state. It encompasses Kittitas County, large portions of Yakima and Benton counties, and a small portion of Klickitat County. The basin is bound by the Cascade Mountains on the west and the Rattlesnake Hills on the east. The Wenatchee Mountains bound the Yakima Basin to the north and the Horse Heaven Hills form the southern boundary of the basin. Figure 14 shows the Yakima Basin and its location in the state of Washington.

The Yakima River and its tributaries (Fig. 14) flow through the Yakima Basin and are the primary sources of surface water for the basin. The Yakima River originates in the rugged Cascade Mountains and flows for about 350 kilometers (215 miles) in a southeasterly direction to its confluence with the Columbia River near Richland (Fig. 14). The average annual discharge from the Yakima Basin is about 2,893 million cubic meters (2,345 million acre-feet) according to a study for the Washington State Department of Ecology by CH_2M-Hill (1975b). The average annual flow leaving the basin would be considerably higher than the actual flow because of diversion of 2,928 million cubic meters (2.4 million acre-feet) of water to irrigate about 220,000 hectares (550,000 acres) of cropland. According to Huszar and co-authors (1978), of the 2,928 million cubic meters (2.4 million acre-feet) diverted for irrigation, 1,410 million cubic meters (1,156 million acre-feet) of irrigation water are consumed by crops, 120 million cubic meters (0.098 million acre-feet) are diverted outside the Yakima Basin, and the remainder become irrigation return flows.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ELLENSBURG
COLUMBIA
CASCADE MTS.
BUMPING LAKE
BUMPING RIVER
ROZA DAM
CLEAR LAKE
RIM ROCK LAKE
TIETON RIVER
YAKIMA
Y A K I M A
SUNNYSIDE DAM
WAPATO
TOPPENISH
TOPPENISH CREEK
SUNNYSIDE
SULPHUR CREEK
B E N T O N
BENTON CITY
KIONA
RICHLAND
RIVER
PROSSER
HORSE HEAVEN HILLS

Figure 14. Map of the Yakima Basin.

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9-1/8"
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The Yakima Basin is characterized by warm, dry summers and cool, wet winters. The irrigated lands in the upper reaches of the Yakima Basin receive from 250 to 380 millimeters (10 to 15 inches) of precipitation, while the lower reaches of the basin receive less than 250 millimeters (10 inches) of precipitation. For example, at Sunnyside (Fig. 14) the annual precipitation is about 178 millimeters (7 inches) according to a report by the U.S. Army Corps of Engineers (1978).

Agriculture is the primary economic activity in the Yakima Basin. The basin contains over 280,000 hectares (700,000 acres) of cropland, of which over 200,000 hectares (500,000 acres) is irrigated cropland (Pacific Northwest River Basins Commission, 1977). Primary crops in the Yakima Basin include apples, cherries, peaches, pears, prunes, sugar beets, grapes, mint, grain, corn, hops, and hay. Livestock and forestry are also important contributors to the economic base of the Yakima Basin.

The major industries in the basin are related primarly to the processing of agricultural products. The city of Yakima is the center for processing of both fruit and vegetable crops grown in the Yakima Basin and adjacent areas.

According to the U.S. Department of Commerce (1977), the Yakima Basin contained over 20% of all the farms in the state of Washington. It is the largest producer of agricultural commodities in the state of Washington. At the farm level, the market value of agricultural commodities sold in the Yakima Basin exceeds $180 million annually (Pacific Northwest River Basins Commission, 1977). In addition, the Yakima Basin is one of the most productive agricultural areas in the U.S. For example, Yakima County ranks first in the U.S. (among all the 3,072 counties) in the production of apples, hops, and mint, and ranks fifth in the U.S. in the value of overall agricultural production (U.S. Department of the Interior, 1977).

The Yakima Basin has historically contained about 7% of the population of the state of Washington (U.S. Department of Commerce, 1973). The largest city in the basin is Yakima (Fig. 14) with about 20% of the population of the basin. About 60% of the residents of the basin live in Yakima County and 10% live in Kittitas County with the remainder living in Benton County. Most of the residents of the basin live in 23 small towns located along the Yakima River. For additional information on the Yakima River Basin, refer to the Pacific Northwest River Basins Commission (1977) study.

CURRENT WATER QUALITY OF THE YAKIMA RIVER

The Yakima River is a multiple use resource serving homes, industry, irrigation, recreation, fish, and wildlife maintenance. The water quality demanded by these uses varies. To assess the current quality of the Yakima River water objectively, one needs standards against which to compare the present water quality of the river.

The Washington State Department of Ecology first published water quality standards in 1973. These standards were revised by the Department of Ecology in December 1977. The Washington State fresh water standards classify all rivers in the state of Washington into one or more categories (class AA, class A, class B, and class C). The standards also provide a fifth classification which applies to lakes and reservoirs called lake class. The classification of a river or portions of a river into these different classes is based on specific water quality criteria. Table 2 gives the fresh water quality standards for the state of Washington. The range of values that are imposed on different water quality parameters (e.g., class AA) are also given in Table 2.

The Yakima River and its tributaries have been placed into three quality classes by the Washington State Department of Ecology. In its headwaters, the first 48 kilometers (30 miles) of the Yakima River from its source downstream is designated as class AA stream. Class AA streams exceed the quality requirements of all types of water uses. Tributaries of the Yakima River in the first 48 kilometers (30 miles) from its source are also designated class AA streams.

The 132 kilometers (82 miles) of the Yakima River below the class AA segment is categorized class A. Tributaries of the river in this segment are also designated class A streams. Class A streams at least meet the quality requirements of all uses.

The last 167 kilometers (104 miles) of the Yakima River is categorized as a class B stream. All the tributaries of the Yakima River in this segment are designated class A except for Sulphur Creek (Fig. 14) which is designated a class B stream. Class B streams meet the quality requirements for most, but not all water uses. The last 167 kilometers of the Yakima River are not fit for contact water recreation (e.g., swimming), according to the Washington state water quality standards (Table 2). In addition, the temperature standard (for class B streams) is also occasionally violated in the last 167 kilometers of the Yakima River.

An examination of the Washington state water quality standards (Table 2) shows that the classification of the Yakima River in the last 167 kilometers (104 miles) as class B stream is based on the measured levels of only six water quality parameters. These parameters are dissolved oxygen, temperature, total dissolved gas saturation, pH, turbidity, and fecal bacteria. However, the standards (Table 2) do not specify values for nitrates and phosphastes which are also important to water quality. Therefore, the current water quality of the Yakima River can better be appraised by augmenting the Washington state water quality standards (Table 2) with the recommended levels (Table 1) for those parameters for which no values were specified by the Washington state water quality standards.

The current water quality of the Yakima River for average flow conditions at selected water quality sampling points along the Yakima River is given in Table 3. For a location of the sampling stations, see Fig. 14. A comparison of the Washington state water quality standards (Table 2)

TABLE 2. WATER QUALITY STANDARDS OF THE STATE OF WASHINGTON

Water quality parameters	Water quality class designations				
	Class AA	Class A	Class B	Class C	Lake class
Dissolved oxygen (mg/l)	9.5[a]	8.0[a]	6.5[a]	---	f
Temperature (°C)	16[b]	18[b]	21[b]	24[b]	f
Total dissolved gas (% of saturation)	110[b]	110[b]	110[b]	110[b]	110[b]
pH (pH units)	6.5-8.5	6.5-8.5	6.5-8.5	6.5-9.0	f
Turbidity (JTU)	5[c]	5[c]	10[d]	10[d]	5[e]
Fecal coliform bacteria (median number per 100 ml)	50	100	200	---	50[b]

[a] Shall exceed values shown.

[b] Shall not exceed values shown.

[c] Shall not exceed values shown over background turbidity when background turbidity is 50 Jackson Turbidity Units (JTU) or less, or have more than a 10% increase when background turbidity is more than 50 JTU.

[d] Same as c, except not to have more than a 20% increase.

[e] Shall not exceed values shown beyond background conditions.

[f] No measurable change from natural conditions.

SOURCE: U.S. Army Corps of Engineers, Seattle District, 1978, Yakima Valley Regional Water Management Study, Vol. 2, Seattle, Washington.

TABLE 3. CURRENT WATER QUALITY OF THE YAKIMA RIVER AT SELECTED LOCATIONS

Water quality parameter	Unit	June	July	August	Three-month average
Yakima River at Cle Elum					
Maximum temperature	°C	11.4	17.2	19.6	16.1
Low stream flow	CMS	36.95	49.55	58.33	48.3
Dissolved oxygen	mg/l	10.1	9.0	8.4	9.2
Fecal coliform bacteria	No./100 ml	NA[a]	NA	NA	16[b]
Nitrate nitrogen	mg/l	0.03	0.01	0.01	0.01
Phosphate phosphorus	mg/l	0.00	0.00	0.00	0.00
Turbidity	JTU	1	1	1	1
Yakima River at Roza Dam					
Maximum temperature	°C	15.5	16.0	16.0	15.8
Low stream flow	CMS	NA	NA	NA	NA
Dissolved oxygen	mg/l	8.7	9.2	9.5	9.1
Fecal coliform bacteria	No./100 ml	NA	NA	NA	NA
Nitrate nitrogen	mg/l	0.12	0.10	0.10	0.10
Phosphate phosphorus	mg/l	0.04	0.04	0.04	0.04
Turbidity	JTU	2	2	2	2
Yakima River at Kiona					
Maximum temperature	°C	18.5	22.5	21.0	20.5
Low stream flow	CMS	35.96	30.16	34.69	33.6
Dissolved oxygen	mg/l	8.5	7.7	7.9	8.0
Fecal coliform bacteria	No./100 ml	NA	NA	NA	174[b]
Nitrate nitrogen	mg/l	0.53	0.78	0.89	0.73
Phosphate phosphorus	mg/l	0.10	0.12	6.13	0.12
Turbidity	JTU	10	10	6	15[b]

[a] NA = not available.

[b] Based on 1975 data from the U.S. Army Corpos of Engineers, Seattle District, 1978, Yakima Valley Regional Water Management Study, Vol. 2, Seattle, WA.

SOURCE: CH_2M-Hill, 1975b, Characterization of Present Water Quality Conditions in the Yakima Basin, Technical Bulletin No. 10, Olympia.

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augmented with Table 1 where applicable and the present flow of the Yakima River under average flow conditions (Table 3) shows that in the upper reaches of the Yakima River (e.g., at Cle Elum in Table 3) the water quality in general complies with the standards for class A stream. In the middle reaches of the Yakima River (e.g., at Roza Dam in Table 3) the water quality standards for class A stream are violated. In the lower reaches of the Yakima River (e.g., at Kiona at Table 3) the water quality standards for class B streams are frequently violated. Below Kiona (Fig. 14) the quality of the Yakima River is degraded to a considerable degree with respect to actual measured levels of dissolved oxygen, temperature, fecal bacteria, nitrates, and phosphates in the river.

CONTRIBUTORS TO WATER QUALITY DEGRADATION

The Yakima River and its tributaries receive discharges of agricultural, municipal, and industrial wastes that contribute to water quality degradation of the river beginning in the upper reaches of the Yakima Basin. According to the Pacific Northwest River Basins Commission (1971, 1977) and EPA (Huszar, 1978), contributors to water quality degradation in the lower Yakima River (between Sunnyside Dam and Richland) include municipalities, industries, irrigation return flows, livestock operations, rural-domestic populations, land use, and natural causes. In the lower Yakima River, the most significant contributor to water quality degradation is the large volume of irrigation return flows that enter the river through canals, drains, and creeks (CH_2M-Hill), 1975b; Sylvester and Seabloom, 1963).

During the summer months, irrigation return flows constitute about 80% of the flow of the lower Yakima River while in the upper and middle reaches (between Ellensburg and Yakima--refer to Fig. 14), irrigation return flows make up only about 5% of the Yakima River flow. At Kiona (FIg. 14), according to CH_2M-Hill (1975b), 67% of the nitrogen present in the river, 40% of the total dissolved solids, and 12% of the total phosphorus in the Yakima River are contributed by irrigation return flows. Clearly, irrigation return flows are a major contributor of nitrogen, phosphorus, and total dissolved solids to the Yakima River below Sunnyside Dam.

DEVELOPING THE EMPIRICAL WATER QUALITY SUBMODEL

The empirical water quality submodel is developed for three selected water uses in the Yakima Basin: irrigation, recreation, and fishing. The choice of only these three water uses is for demonstrative purposes. However, the choice of only these three uses can also be defended on other grounds. Economists who have worked in the area of environmental economics (Kneese and Bower, 1979; Krutilla, 1966; Knetsch and Davis, 1966; Freeman, 1979; Sinden and Worrell, 1979; Reiling, Gibbs and Stoevener, 1973; Davidson, Adams, and Seneca, 1966) feel that the major benefits from environmental quality improvements accrue to recreational and fishing uses. Municipal and industrial uses do not benefit much from river water quality improvements. The reason, according to Freeman (1979) is that municipalities supplying water to homes and industries have to treat the water before supplying it whether the river quality has been improved or not. Because of this, the savings that accrue to municipalities due to river water quality improvements may be small. This, however, is not to suggest that municipalities and industries do not benefit from water quality improvements, but just to indicate that the benefit is most likely small.

In the Yakima Basin, most of the municipalities (20 out of 23) and industries obtain their water from groundwater (Pacific Northwest River Basins Commissions, 1977). Nitrate is the only major pollutant that enters groundwater from irrigation return flow. Thus, even the quality of their water source would be little affected by the Yakima River. It appears that the exclusion of these two uses would not do great damage to an empirical study of water improvement benefits in the Yakima Basin.

The first step in the development of an empirical water quality submodel is the construction of water use quality indices for each of the three water uses. To construct the water quality indices, however, one needs to know the relevant water quality parameters that affect the usefulness of the Yakima River for each of the three uses. The question now is, how can the relevant water quality parameters for each of the three uses be determined?

An approach for selecting parameters to be included in a water quality index and specifying water quality index functional forms was suggested by Brown, McClelland, Deninger, and Tozer (1970). Brown and co-authors used the Delphi method[1] to combine the opinions of a large number of water experts from throughout the U.S. to accomplish three things: (1) determine water quality parameters that are of greatest importance according to the water quality experts, (2) determine weights (importance) that are to be attached to each water quality parameter, and (3) determine functional relations between water quality parameters and the water quality index. They found that dissolved oxygen, fecal coliform bacteria, pH, 5-day biochemical oxygen demand, nitrates, phosphates, temperature, turbidity, total solids, toxic substances, and pesticides are water quality parameters of great importance. The authors determined that the weight (importance in affecting water quality) attached to dissolved oxygen was 0.17 while total solids and turbidity were assigned the lowest weight of 0.08. The weights on all the first nine water quality parameters sum to unity. No weights and functional forms were reported for toxic substances and pesticides

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[1] The Delphi method is a general procedure used to pool the informed judgments of a panel of experts to obtain information about some subject (e.g., water quality). The procedure works as follows. Each of the experts is consulted (e.g., by means of mail questionnaire) and their responses are summarized in a statistical form and presented to all experts. The experts are then asked to revise their judgement on the basis of of the summary of all responses. The process is continued until a consensus of expert opinion emerges on the subject. The interested reader should refer to Linstone and Turoff (1975). For applications of the Delphi method to economic problems refer to Intriligator (1978).

The major problem with the water quality index developed by Brown and co-authors, known as the National Santitation Foundation Water Qaulity Index (NSFWQI), is that it is a general purpose water quality index. It does not recognize that the water quality requirements of different uses vary and different parameters are relevant for different uses. Because of this problem, the NSFWQI cannot be adapted to this study.

The water quality submodel developed for the Yakima River selected eight water quality parameters that are considered important for inclusion in the construction of water quality indices for irrigation, recreation, and fishing uses. The selection of these eight water quality parameters was based on five sources of information:

1. Careful examination of water quality data on the Yakima River at selected points.

2. Examination of previous water quality studies on the Yakima River.

3. Visits with the Washington State Department of Ecology personnel.

4. Interviews with knowledgeable researchers on the quality of the Yakima River at Washington State University and the University of Washington.

5. Examination of other relevant scientific literature on water quality such as National Academy of Sciences (1973) and U.S. Environmental Protection Agency (1976).

For a parameter to be included in the water quality index for a particular use, two conditions must hold. First, there must be scientific evidence that the parameter has a significant effect on the specific water use. Second, the measured level of the parameter must violate water quality standards (Talbes 1 and 2) established for that use. In other words, the specific water quality parameter should limit water use.

The water quality parameters selected for inclusion in the water quality indices for irrigation, recreation, and fishing uses of the Yakima River are:

X_1 = farm delivery sediment concentration in milligrams per liter (mg/l).

X_2 = median number of fecal coliform bacteria per 100 milliliters.

X_3 = dissolved oxygen concentration in mg/l.

X_4 = water temperature in degrees Celsius.

X_5 = nitrate-nitrogen concentration in mg/l.

X_6 = phosphate-phosphorus concentration in mg/l.

X_7 = stream flow in cubic meters per second.

X_8 = turbidity in Jackson Turbidity Units.

Each of the eight water quality parameters affects agricultural, recreational, and fish and wildlife maintenance uses of the Yakima River differently. It is known that the effects of these parameters are not independent. The background discussion in Section 5 pointed out that fishing water uses are affected by low stream flows, high sediment and suspended solids in the river, high water temperature, low dissolved oxygen levels, and presence of fecal coliform bacteria in the water. Furthermore, it was also indicated that recreational water use is adversely affected by low stream flows, large numbers of fecal bacteria, high concentrations of nitrates and phosphates, and a high sediment and suspended solids concentration.

Agricultural water uses are adversely affected by the presence of sediments, weed seeds, mosses, and other aquatic plants that may be in the irrigation water delivered to farms. In addition, the temperature of the irrigation water is also important for the growth of weeds and other nuisance plants on the banks of water delivery systems.

Since the concern of this study is improving the quality of the river, one need not be concerned with non-limiting parameters whose increased levels have either neutral or beneficial effects for a specific water use. Instead, one should concentrate on those parameters that limit each water use. For example, pH is an important water quality parameter for recreational and fishing uses. But examination of the level of this parameter in the Yakima River revealed that it is within acceptable levels for these uses. Consequently, it will not be included in the recreation and fishing water quality indices.

For the three water uses chosen for study in the Yakima Basin, the overall water use quality index functions (Q_k^r) based on water quality parameters that limit water use k in river reach r may be specified as follows:

$$Q_1^r = \min\{I_{12}^r, I_{17}^r, I_{18}^r\} \quad (6.1)$$

$$Q_2^r = \min\{I_{22}^r, I_{24}^r, I_{25}^r, I_{26}^r, I_{27}^r, I_{28}^r\} \quad (6.2)$$

$$Q_3^r = \min\{I_{32}^r, I_{33}^r, I_{34}^r, I_{35}^r, I_{36}^r, I_{37}^r, I_{38}^r\} \quad (6.3)$$

where

Q_1^r = minimum water quality index for agricultural use (k=1) in river reach r

Q_2^r = minimum water quality index for recreational use (k=2) in river reach r

Q_3^r = minimum water quality index for fishing use (k=3) in river reach r

I_{kj}^r = water quality index for water use type k=1,2,3 and water quality parameter j=1,2,3, ..., 8. For example in Equation 5.1 I_{12}^r refers to the water quality index for agricultural use (k=1) due to X_2, j=2.

It was necessary to obtain water quality index functions (I_{kj}^r) for each of the three water uses with respect to the eight water quality parameters (X_j). Water quality parameters to be included in the water quality index function for each use were chosen based on the five sources and two criteria specified in the preceding section. Where information was available, the scientific literature was reviewed to determine what level of a pollutant (as measured by a water quality parameter) is considered high, medium, and low. Where information was not available, the opinions of knowledgeable scientists were used to judge these qualities. Based on these pieces of information, the simplest possible functional forms (mostly linear) relating water quality (I_{kj}^r) to the level of a pollutant X_j (as measured by a water quality parameter) were chosen. Interaction among pollutants was ignored. Instead, it was assumed that the action of one pollutant is independent of others. For example, there is a definite relationship between the levels of dissolved oxygen in a river and water temperature. In fact, this relationship is given by Liptak (1974) as

$$(6.4) \quad DO = 10,087.53 - 129, 62761A + 0.62758425A^2 - (1.3545821 \times 10^{-3})A^3 + (1.09878 \times 10^{-6})A^4$$

where DO = dissolved oxygen concentration at saturation in mg/l and A is temperature in degrees Kelvin[2] (O_k). Interaction among pollutants was not considered because of lack of accurate scientific information about the combined effect of the various pollutants.

The water quality index functions chosen for the Yakima River were presented to a panel of knowledgeable scientists[3] for review. Based on the panel review, variables were added or dropped, different levels of pollutants (high, medium, and low) were adjusted, and functional forms were altered. The water quality index functions to be presented in the subsequent sections are the result of this process.

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[2] K = C +273. For example, 68°F = 20°C = 293°K.

[3] The panel include Brian L. McNeal, Professor of Soils; Larry King, Professor of Agricultural Engineering; Richard Richter, Professor of Environmental Engineering; and Gary Bailey, Environmental Scientist, (fisheries), Washington State University.

DEVELOPING WATER QUALITY INDICES FOR AGRICULTURAL USE

This section develops water quality indices for agricultural use of water diverted from the Yakima River for irrigation with respect to sediment concentration in irrigation water delivered to the farm headgate (X_1), irrigation water temperature (X_4), and instream water flow (X_7). The procedure followed is to develop an agricultural use index for each water quality parameter.

Table 4 provides a descriptive and numerical definition of different water quality levels for agricultural uses. For example, irrigation water that contains no sediment and is of sufficiently low temperature to inhibit weed growth in ditches is said to be of perfect water quality. Irrigation water with perfect water quality is assigned a water quality index value of 100.

Sediment (X_1)

According to Carlile (1972) sediment pollution has become an ever-worsening problem in downstream diversion canals and in the lower Yakima River itself. Canals and laterals carrying irrigation water to farms often receive an inflow of sediments directly from other farms in the lower Yakima River, particularly in the Sunnyside Valley Irrigation District.[4]

For example, the Sunnyside Canal receives 0.707 cubic meters per second (25 cubic feet per second) of return flow directly from the Sulphur Creek drainage (CH_2M-Hill, 1975a, Table 4). Thus, these irrigation return flows containing sediment and other pollutants increase the sediment content of irrigation water. Some of the sediment is deposited in canal laterals and ditches, and the remaining sediment in the irrigation water affects pumps, sprinkler heads, and pipes.

Data from King and co-authors (1977) showed that, in general, irrigated fields in the Sunnyside Valley Irrigation District received irrigation water with considerably more sediment content than fields in the Roza Irrigation District.[5] For nine selected fields in the Sunnyside Valley

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[4] The Sunnyside Valley Irrigation District contains 34,500 hectares (84,860 acres) of irrigated farmland in the lower Yakima River and receives its water from the Sunnyside Canal and its laterals. The Sunnyside Valley Irrigation District also provides irrigation water to eight other smaller irrigation districts.

[5] The Roza Irrigation District is located in the lower Yakima Basin and covers an area of about 29,000 hectares (72,500 acres) and is supplied by the Roza Canal. Data from King and co-authors (1977) for selected fields in the Roza District showed that the average sediment content of irrigation water delivered to these fields was 15 mg/a and it ranged from 0 to 119 mg/l.

TABLE 4. DESCRIPTIVE AND NUMERICAL DEFINITIONS OF DIFFERENT WATER QUALITY LEVELS FOR AGRICULTURAL WATER USE IN THE YAKIMA BASIN

Quality level descriptions	Agricultural quality index
Perfect Water Quality No sediment or plant growth exists to damage irrigation equipment, or prevent use on any crop. Such water does not leave sediments in supply ditches, and thus ditch cleaning is not required for this reason.	100
Very Good Water Quality This water contains a small amount of sediments showing occasional turbidity. No significant damage to sprinkler parts will be caused. Some filtering or treatment will be required before use in drip or trickle irrigation systems. Supply ditches require cleaning once in 5 years.	86-99
Good Water Quality This water contains some sediments to cause damage to sprinkler systems. It may reduce the life expectancy of sprinkler nozzle and pump impellers by about 25%. Supply ditches need to be cleaned every 2-3 years due to sedimentation.	60-85
Poor Water Quality Such water contains a substantial amount of sediments. Supply ditches need to be cleaned or flushed several times during a growing season. Check dams may have to be flushed daily to avoid excessive sediment build-up. The water must be settled before use in sprinkler systems and the life expectancy of sprinkler nozzle and impellers are reduced to about 45% of normal. Such water is unsuitable for trickle irrigation.	30-59
Very Poor Water Quality The water contains a very large sediment load. It is unsuitable for both drip and sprinkler irrigation. If the water is used in a sprinkler system, the wear on parts would be quite rapid and there could be substantial damage to certain fruit and vegetable crops from sediment accumulation.	0-29

Irrigation District that received irrigation water from the Sunnyside Valley Canal, the mean sediment concentration in the irrigation water was found to be 171 mg/l at the farm headgate and the range was from 91 to 277 mg/l. In its upper reaches irrigation water from the Sunnyside Canal contains considerably less than 171 mg/l, showing that the difference is picked up from irrigation return flows that empty into the canal. The same is also true of the Roza Canal.

Sediment in irrigation supply ditches and in irrigation water cause problems for the farmer. Sediments deposited in irrigation ditches stimulate the growth of weeds and other nuisance plants, provided that the water temperature is warm. In addition, the presence of sediment in the irrigation water supply system interferes with the proper functioning of the irrigation supply system by reducing the volume of water that it can transport, possibly leading to water loss. Moreover, sediment in irrigation water also leads to added sprinkler system repair costs.

A progress report by Bowhay (1980) examined the effect of best management practices (for example, construction of a sediment settling pond) on the quality of irrigation return flows leaving farms. Bowhay reported that in the Sulphur Creek Drainage of the lower Yakima River, some farms received irrigation water from the Roza Canal containing sediment with about 35 mg/l and returned water containing sediment concentrations ranging from 695 to 1183 mg/l to the drains during the month of May for non-sprinkler irrigated fields. Return flows emptying into a sediment pond were observed containing sediment concentrations that ranged from 704 mg/l to 1338 mg/l. For one of the drains, Bowhay reported sediment concentrations as high as 4463 mg/l. For some farms, these high concentrations of sediment are delivered to the headgate and must be used as irrigation water. In most cases, however, water diverted from the river has much lower levels of sediment concentrations.

A review of the literature did not reveal any standards, limits, or recommendations for the level of sediment in irrigation water. Researchers[6] who are familiar with the Yakima Basin and have made water quality studies on some aspects of the Yakima Basin feel that irrigation water delivered to farms with less than 50 mg/l of sediment must be considered to be of good quality, while irrigation water with over 500 mg/l of sediment is of poor quality, and irrigation water with more than 1000 mg/l is of very poor quality. Definitions of the terms perfect, very good, good, poor, and very poor water quality for the Yakima River in irrigation use were given in Table 4.

Using the above information, the following linear water quality index functions were chosen for X_1.

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[6] Brian L. McNeal, Professor of Soils, Washington State University (WSU), and Larry G. King, Professor of Agricultural Engineering, WSU.

$$(6.5) \qquad I_{11} = \begin{cases} 100 & (X_1 < 20) \\ 140 - 2X_1 & (20 \leq X_1 \leq 25) \\ 90 - 0.079\, X_1 & (25 < X_1 \leq 1088) \\ 0 & (X_1 > 1089) \end{cases}$$

Note that in Equation 6.5 the values of I_{11} range from 0 to 100. A water quality index value of 100 corresponds to perfect water quality (no pollution) and zero represents very poor water quality (extreme pollution).

Temperature (X_4)

Warmer temperatures in irrigation canals and drains combined with increased levels of plant nutrients (nitrogen and phosphorus fertilizers) promote plant growth along irrigation canals and drains. It is assumed that the temperature of the irrigation water (X_4) is influenced by the amount of water flow in the river. At the point of diversion, the irrigation water has the same temperature as the river. Here it is assumed that the temperature of the irrigation water (X_4) is influenced only by the amount of water flow (X_7) in the Yakima River. That is,

$$(6.6) \qquad X_4 = f(X_7)$$

This relationship was estimated to be

$$(6.7) \qquad X_4 = 24.0 - .0565\, X_7$$

Equation 6.7 is based on calculations adopted from Pfeiffer (1976).

A review of the literature did not reveal specific numerical limits on temperature of irrigation water. In view of this lack of information, the following water quality index function was used:

$$(6.8) \qquad I_{14} = \begin{cases} 209 - 6.8125\, X_4 & (X_4 > 16) \\ 100 & (X_4 < 16) \end{cases}$$

WATER QUALITY INDICES FOR WATER ORIENTED OUTDOOR RECREATIONAL USE

This section develops water quality indices for recreational use with respect to (1) coliform bacteria, (2) water temperature, (3) nitrate nitrogen, (4) phosphate-phosphorus, (5) instream sediment, and (6) stream flow. In developing the indices for each parameter the discussion will be brief since a background discussion was given on the major pollutants originating in the agricultural sector and their effects in the first section of Section 5. Table 5 gives a descriptive and numerical definition of different water quality levels for recreational use in the Yakima Basin.

Fecal Coliform Bacteria (X_2)

Fecal coliform bacteria in recreational water are of concern because fecal coliform bacteria are found only in the intestinal tract of warm-blooded animals including humans. Since people are susceptible to many intestinal diseases, fecal coliform bacteria count is a good indicator of the possible health hazard.

The Washington State Department of Ecology water quality standards for fecal coliform bacteria were given in Table 2. The standards require that fecal bacterial count must not exceed 50 bacteria, 100 bacteria, and 200 bacteria per 100 ml in class AA, class A, and class B streams, respectively. Based on this information and the definitions given in Table 5, the following water quality index functions have been selected.

$$I_{22} = \begin{cases} 100 - 0.26\, X_2 & (0 \le X_2 \le 384) \\ 0 & (X_2 > 384) \end{cases} \tag{6.9}$$

Stream Flow and Water Temperature

Water recreational activities in a river can take place only in the presence of adequate stream flow. Recreational skills and water flow are complementary to recreational participation and enjoyment. Depending on the activities in which they engage, recreationists require a certain minimum flow to participate in their specific recreational activity such as boating or swimming. The quantity of water flowing in a stream is an important determinant of its quality and water temperature. A function relating water temperature to the quantity of water flowing in the Yakima River was given in Equation 6.7.

The following water quality index combines both temperature and quantity to stream flow.

$$I_{24} = \begin{cases} -356.88 + 49.80\, X_4 - 1.36\, X_4^2 & (10 < X_4 < 27) \\ 100 & (X_7 > 100.72878 \text{ cubic meters}) \\ 0 & (X_4 > 27 \text{ and } X_4 < 10) \end{cases} \tag{6.10}$$

where X_4 is given by Equation 6.7.

Nitrate-Nitrogen (X_5)

Nitrogen is present in streams as nitrate (NO_3-N), nitrite (NO_2-N), or ammonia (NH_3-N). The concentration of the nitrate form of nitrogen is

TABLE 5. DESCRIPTIVE AND NUMERICAL DEFINITIONS OF DIFFERENT WATER QUALITY LEVELS FOR RECREATIONAL WATER USE IN THE YAKIMA BASIN

Quality level descriptions	Recreation quality index
Perfect Water Quality The river can be used for both contact and non-contact water recreation. It is perfectly clear and contains no sediments, nutrients, bacteria, weeds, or other contaminants. It supports all forms of desirable aquatic life.	100
Very Good Water Quality The river is fit for both contact and non-contact water recreation. However, it contains a small amount of one or more of the following: sediments, nutrients, bacteria, weeds, and organic wastes. It supports most desirable forms of aquatic life.	86-99
Good Water Quality The river is fit only for non-contact water recreation such as fishing, sightseeing, or boating. It cannot be used as a rearing ground for migrant fish such as salmon, but may allow the migration of adult salmon or steelhead. Such water contains a considerable amount of one or more of the following: sediments, nutrients, bacteria, aquatic weeds, and organic wastes. It supports some desirable forms of aquatic life.	60-85
Poor Water Quality The river is unacceptable for contact recreation such as swimming, and is rarely used for non-contact water recreation. It cannot support most desirable aquatic life forms. It contains a large amount of one or more of the following: sediments, nutrients, bacteria, aquatic weeds, and organic wastes.	30-59
Very Poor Water Quality The river cannot be used for either contact or non-contact water recreation. It cannot support most desirable aquatic life forms. It contains a very large amount of one or more of the following: sediments, nutrients, bacteria, aquatic weeds, and organic wastes. Such a river is primarily used as a waste receptor.	0-29

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of concern because in this form it is readily available for plant growth. Thus, a large concentration level may enhance the growth of undesirable aquatic plants and weeds which may interfere with recreational use of the stream. Excessive aquatic plant growth may also contribute to reduced oxygen levels in the stream which leads to depressed biological productivity of the stream.

Nitrate-nitrogen levels in the lower Yakima River have increased 500 percent[7] in the last 20 years, and are mainly attributed to the increased use of fertilizer in agriculture for crop production (CH_2M-Hill, 1975b). A report by CH_2M-Hill (1975b) has shown that in the 2875 hectare Sulphur Creek drainage basin of the lower Yakima each hectare of irrigated land loses about 35 kilograms of nitrogen (30 lb per acre).

Sawyer (1947) determined the critical levels of nitrate for algal bloom to be 0.30 mg/l. Based on Sawyer's work the U.S. Environmental Protection Agency (1976) has suggested that the levels of nitrate-nitrogen not exceed 0.30 mg/l in the lower Yakima River. Below Mabton (see Fig. 14 for location), the nitrate-nitrogen concentration of the Yakima River is more than twice the suggested level (Table 3).

The nitrite form of nitrogen (NO_2-N) and the ammonia form of nitrogen (NH_3-N) are not at problem levels of concentration in the lower Yakima River.

The aquatic nuisance plants which affect recreation begin to grow when the nitrate level exceeds 0.30 mg/l. However, it is the simultaneous presence of nitrates and phosphates in excess of the recommended levels under the appropriate conditions that promotes the growth of nuisance aquatic plants. Phosphate-phosphorus is considered by many scientists as the one nutrient most frequently constraining the growth of aquatic plants (Schindler, 1977). Nitrogen is the nutrient considered as the next most limiting of algal growth (Dunne and Leopold, 1978).

The following linear water quality index functions have been chosen for nitrate-nitrogen in recreational use.

$$(6.11) \qquad I_{25} = \begin{cases} 100 - 40.2\,X_5 & (0 \le \le 0.87) \\ 65 - 6.5\,X_5 & (0.87 < X_5 \le 10) \\ 0 & (X_5 \ge 10) \end{cases}$$

Phosphate-Phosphorus (X_6)

Phosphorus as phosphate is one of the key nutrients needed for plant growth. Excessive amounts of phosphate-phosphorus in water bodies leads to objectionable plant growth when other growth promoting factors are available.

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[7] The average August nitrate concentration in the Yakima River near Benton city (Fig. 14) increased from 0.2 mg/l in 1953 to 1.2 mg/l in 1974 (CH_2M-Hill, 1975b).

According to Schindler (1977) phosphate is often considered as the limiting nutrient for plant growth in streams. The National Academy of Sciences (1973), based on the works of Sawyer (1947), has recommended that phosphate-phosphorus in water bodies not exceed 0.01 mg/l to avoid the risk of algae bloom. The National Academy of Sciences also has recommended that the level of total phosphorus not to exceed 0.05 mg/l in streams. In the lower Yakima River, below Sunnyside Dam the phosphate-phosphorus concentration of the Yakima Rive exceeds the suggested maximum of 0.01 mg/l. At Kiona (Fig. 14 for location), the phosphate level is 0.06 mg/l (Table 3) which is six times the suggested level. The following index function was chosen for phosphate.

$$I_{26} = \begin{cases} 100 - 291.66\, X_6 & (0 \le X_6 \le 0.34) \\ 0 & (X_6 > 0.34) \end{cases} \tag{6.12}$$

Instream Turbidity (X_8)

Sediment renders water aesthetically unpleasing. In large quantities, it may limit the biological productivity and aquatic life the river will sustain for enjoyment of people. This is primarily because sediment reduces the clarity and limits light penetration of the water which may become objectionable to the recreationist.

The Washington State Department of Ecology specified standards for instream turbidity, but not instream sediment concentrations (Table 2). The Washington state water quality standards require that turbidity should not exceed 5 JTU in Class AA streams. In Class A streams, the water quality standards require that turbidity should not exceed 10 JTU. Assuming that a turbidity level of 5 JTU corresponds to a very good water quality, and zero turbidity level corresponds to perfect water quality, the resulting index for turbidity becomes:

$$I_{28} = \begin{cases} 100 - 2.72\, X_8 & (0 \le X_8 \le 36) \\ 0 & (X_8 > 36) \end{cases} \tag{6.13}$$

It is believed that turbidity increases with suspended solids concentration, but not as fast as suspended solids (Dunne and Leopold, 1978). Typical relations between turbidity and sediment concentrations were given by Emmett (1975) as

$$t = CG^n \tag{6.14}$$

where t is turbidity measured in Jackson Turbidity Units (JTU), G is suspended sediment concentration in mg/l, C is a coefficient varying between 0.7 and 1.3, and n is an exponent lying between 0.6 and 0.7. Thus, by making reasonable assumptions about C and n, one can compute the value of t that corresponds to C in Equation 6.14. Similarly, for a given value of t the corresponding value of G can be computed.

King, Basset, and Ebeling (1978), however, challenged the statistical reliability and accuracy of a functional relationship between turbidity and sediment concentration, such as the one given in Equation 6.14. They studied the relationships between turbidity (measured in JTU) and sediment concentration (measured in mg/l) in three different farming areas in the state of Washington. Attempts were made to fit the field data from each area to alternative functional forms. The authors found that a linear functional form instead of the power function of the form given in Equation 6.14 resulted in the best statistical fit. In addition, the authors found that coefficients between sediment and turbidity were too low to be of use in predicting sediment yield with any degree of accuracy. The authors recommended that sediment be measured directly as a water quality parameter, even though monitoring sediment concentration is both costly and time consuming, while turbidity is easily measured.

WATER QUALITY FOR FISHING

This section develops the water quality indices for fishing in the Yakima River with respect to (1) bacteria, (2) dissolved oxygen, (3) water temperature, (4) nitrate-nitrogen, (5) phosphate-phosphorus, (6) stream flow, and (7) instream sediment concentration. The procedure followed in developing the water quality indices for fishing is similar to the procedure used for irrigation and recreational uses. Table 6 gives the descriptive and numerical definitions for different water quality levels for fishing use in the Yakima Basin.

Stream Flow and Temperature (X_4, X_7)

Fish and other aquatic life forms cannot survive without water. To thrive, fish and other aquatic life forms require that a certain minimum stream flow never be violated. For fish and other aquatic communities, it is not an average flow that is important, but rather the instantaneous minimum flows.

Bell and Mar (1974) and Pacific Northwest River Basins Commission (1977) have identified low flow problem areas of the Yakima River. These are the areas directly below the major irrigation diversion dams on the main stem of the Yakima River: Horn Rapids, Prosser, Sunnyside, and Wapato. Based on the flow data from 1926-77, the flow of the Yakima River below Sunnyside Dam during the month of August has ranged from a minimum of 1.61 cubic meters per second (57 cubic feet per second) to a maximum of 3.54 cubic meters per second (125 cubic feet per second), and the average flow has been 3.37 cubic meters per second (119 cubic feet per second) according to U.S. Department of Interior (1979).

According to the U.S. Department of Interior (1979), optimum minimum instantaneous flows for the Yakima River below Sunnyside and Prosser Diversion Dams are each 17 cubic meters per second (600 CFS) year round to maintain a healthy anadromous (e.g., salmon) and resident fishery. The same report shows that the optimum minimum instantaneous flow below Kiona

TABLE 6. DESCRIPTIVE AND NUMERICAL DEFINITIONS OF DIFFERENT WATER QUALITY LEVELS FOR FISHING USE IN THE YAKIMA BASIN

Quality level descriptions	Fishing quality index
Perfect Water Quality The river is absolutely clear and does not contain pollutants that would harm fish. There is an adequate flow to support all species of sport fish and no man-made structures that would interfere with fish movement.	100
Very Good Quality The river is clear; however, it may contain a very small amount of sediments or other pollutants. There is an adequate flow to support all locally adaptable species of sport fish, but with lower productivity than perfect water quality.	86-99
Good Water Quality The river has reduced clarity due to considerable amounts of sediments and other pollutants. There is low or inadequate flow during some periods of the year and, thus, the river can support only a limited number of species of sport fish. There may be man-made structures without appropriate fish passage that interfere with fish movement. The productivity of resident sport fish is low and supported only by hatchery reared fish.	60-85
Poor Water Quality The clarity of the river is substantially reduced by sediments, suspended solids, and aquatic weeds. The flow is inadequate for large parts of the year and the river, thus, can support only limited numbers of rough fish. There may be man-made structures without appropriate fish passages that increase the mortality rates of migrant fish like salmon and trout.	30-59
Very Poor Water Quality The river cannot support any desirable fish species because of high levels of sediments and other pollutants. The flow is inadequate and water temperature is high with little oxygen. The river is not fit for fishing but may be used as a waste dump.	0-29

should be 25.5 cubic meters (900 CFS) year round to maintain a sound anadromous and resident fishery in the lower Yakima River.

The resident and anadromous fisheries habitat of the Yakima River has declined significantly since the 1800s with the greatest decline coinciding with the period of initial irrigation development (Pacific Northwest River Basins Commission, 1977). The present anadromous fish runs in the Yakima River constitute less than 5% of the pre-1890 runs. Carp and squawfish dominate the fish population of the lower Yakima River. Sockeye salmon no longer exist in the Yakima River, and Coho salmon are very few in numbers, about 400 according to Bell and Mar (1974).

Water temperature affects all metabolic and reproductive activities of fish. It also affects critical functions like growth, swimming, and the ability to capture and assimilate food. Fish vary in their tolerances to water temperature. Some fish like carp, catfish, and barbel thrive in warm water while most game and sport species like trout prefer colder temperatures. The optimal temperature for trout ranges from 10°C (50°F) to 15°C (59°F), according to Vostradovsky (1973). Bell and Mar (1974) have recommended that for steelhead trout the optimal temperature range should be from 5.6°C (42°F) to 13.3°C (56°F) in the Yakima River. The Washington State Department of Ecology water quality standards for maximum temperature are 16°C (60.8°F), 18°C (64.4°F), and 21°C (69.8°F) for class AA, class A, and class B streams, respectively (Table 2).

In the Yakima River Basin, trout is the most important sport fish from the salmonoid species. Trout accounts for two-thirds of the total fish catch in the Yakima River (Bell and Mar, 1974).

Although other factors such as vegetation cover and channel shape may also be important in determining water temperature in a river, it is assumed in this study for manageability that the quantity of water flow determines water temperature.

Using the relationship in Equation 6.7, the water quality temperature index for rating the fishing uses of the Yakima River is given by

$$(6.17)\quad I_{34} = \begin{array}{ll} 55.56 + 7.41\ X_4 - 0.31\ X_4^2 & (X_7 < 213.245789 \text{ cubic meters}) \\ 100 & (X_7 > 213.245789 \text{ cubic meters}) \end{array}$$

Dissolved Oxygen (X_3)

Fish need dissolved oxygen to sustain species reproduction and growth. Decreased dissolved oxygen levels cause fish to experience stress. As a result, fish become less competitive and less able to sustain their species. A comprehensive study by Doudoroff and Shumway (1970) is considered as the most advanced summary of scientific research on oxygen needs of different species of fish. The National Academy of Sciences (1973) used the study by Doudoroff and Shumway (1970) as the basis for recommendations on dissolved oxygen levels.

The National Academy of Sciences (1973) has recommended that minimum dissolved oxygen levels in streams should not be less than 4 mg/l to prevent chronic damages to fish. Bell and Mar (1974) in their study of the Yakima River fishery recommended that the minimum dissolved oxygen levels be at least 5 mg/l. On the other hand, the Washington State Department of Ecology (Table 2) recommended that the minimum dissolved oxygen levels be 0.5 mg/l, 8.0 mg/l and 6.5 mg/l for class AA, class A, and class B streams, respectively.

The National Academy of Sciences (1973) has recommended that dissolved oxygen levels in streams be taken during pre-dawn hours when oxygen level is at its lowest. Taking dissolved oxygen levels during daylight hours tends to bias the measured level towards higher levels. Dissolved oxygen data in the Yakima River were taken during daylight hours and, consequently, are most likely biased upwards. No adjustments were made, as it was not clear how dissolved oxygen levels vary with the time of day.

Dissolved oxygen concentration, however, varies with water temperature. The functional relationship between dissolved oxygen and water temperature was given by Liptak (1974) as in Equation 6.4. Equation 6.4, however, is somewhat complicated for the purposes of this study. A much simpler function, based on water flow and quality data in the lower Yakima River from April to October, was derived. It is given as

$$X_3 = 12.9436 - 0.2404\ X_4 \tag{6.16}$$

The water quality index functions for fishing use of the Yakima River with respect to dissolved oxygen levels are functionally given as:

$$I_{33} = \begin{cases} 100 & (X_3 > 8.9) \\ 13.2\ X_3 - 18 & (1.37 < X_3 \leq 8.9) \\ 0 & (X_3 < 1.37) \end{cases} \tag{6.17}$$

where X_3 is determined from Equation 6.16.

Instream Turbidity (X_8)

Sediment inhibits light penetration of the water and oxygen transfer. It may also be deposited on fish eggs and other aquatic life forms which serve as food for fish. Sediment reduces visibility in a stream. Reduction of visibility affects fish, as they are sight-feeders. Significant increases in turbidity result in dramatic fish yield reductions. Buck (1956) studied the effect of increased turbidity on fish growth. He found that the yields of fish per hectare showed a decline of nearly 82% as turbidity increased from less than 25 mg/l to over 100 mg/l.

The National Academy of Sciences (1973) recommended that for maximum protection of fish and other aquatic communities streams should contain less than 25 mg/l of sediment. For moderate protection, the sediment concentration should not exceed 80 mg/l of sediment. Streams containing 400 mg/l or more provide low levels of protection for fish.

Based on recommendations of the National Academy of Sciences (1973), the following water quality index functions have been chosen for turbidity levels in the Yakima River.

$$I_{38} = \begin{cases} 100 - 1.72\,X_8 & (0 \leq X_8 \leq 58) \\ 0 & (X_8 > 58) \end{cases} \tag{6.18}$$

Other Conditions

The same quality index functions developed for recreational use of the Yakima River are adopted for fishing use with respect to fecal coliform bacteria, nitrate-nitrogen, and phosphate-phosphorus.

DETERMINATION OF OVERALL WATER USE QUALITY INDEX

Water quality parameters that affect water use for agricultural, recreational, and fishing uses of the Yakima River were specified in Equations 6.1, 6.2, and 6.3 respectively. The discussion in the previous sections derived the water quality indices (I_{kj}) for three selected water uses and eight water quality parameters. That is, the relationships between water quality index I_{kj} for a specific use k and water quality parameter X_j are known.

$$I_{kj} = f(X_j) \qquad \begin{array}{l} k = 1,2,3 \\ j = 1,2,3, \ldots, 8 \end{array} \tag{6.19}$$

In Section 5, the overall water use quality index Q_k^r for use k in river reach r was defined in Equation 5.4 as

$$Q_k^r = \Phi[f(X_j)]$$

and Equation 5.15 gives some of the plausible forms that Φ may assume. The advantages and disadvantages of selecting a specific form for Φ were discussed in Section 5. It should be kept in mind that different forms of Φ are appropriate under different sets of circumstances.

The water quality submodel for the Yakima River employs the minimum operator as the aggregation form for determining the overall water use quality Q_k from the relevant I_{kj}. That is,

$$Q_k = \mathrm{MIN}(I_{kj}) \qquad \begin{array}{l} j = 1,2,3, \ldots, 8 \\ k = 1,2,3 \end{array} \tag{6.20}$$

where MIN stands for the minimum operator which selects the minimum value of I_{kj} as being the value that Q_k assumes. Note that in Equation 6.20, r has been dropped since only one river reach is being considered.

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The minimum operator was chosen as the aggregation rule for several reasons. It is a flexible aggregation form. As long as there are water quality data and water quality rating functions for each water quality parameter, they can be easily incorporated into the overall water use quality index Q_k. There is no limit to the number of water quality parameters that can be incorporated in the overall water use quality index function Q_k. This rule provides insight into water quality management problems by selecting the water quality index I_{kj} that is limiting water use. This information is useful when there is more than one water quality parameter to monitor.

The minimum operator as an aggregation form minimizes the loss of information on water quality variables. It shows the level of other pollutants while concentrating on the limiting pollutant. However, the minimum operator is a conservative water quality index. It may understate actual water quality by concentrating on the critical parameter. The minimum operator also implicitly assigns equal weights to all pollutants (measured by water quality parameters).

The minimum operator is capable of handling interactions that may exist among water quality parameters. In this analysis, however, an assumption of independence among water quality parameters was used because of insufficient information regarding interaction among such parameters.

DEVELOPING THE EMPIRICAL ECONOMIC SUBMODEL

To be operational, the economic submodel presented in Section 5 requires information on:

1. Types of water use.
2. Water quality.
3. Individual valuation of water quality.
4. Number of beneficiaries.
5. Weights to be attached to benefits accruing to poeple with different income levels.

This study selected three types of water use (irrigation, recreation, and fishing) in the Yakima River Basin to demonstrate the application of the analytical model. Data on selected water quality parameters for the Yakima River at selected locations is shown in Table 3.

Individual Valuation of Water Quality

Data on the water users' perceptions of water quality and valuation of water quality were obtained through a mail survey conducted during the summer of 1980. The questionnaires mailed to samples of farmers, recreationists, and fishermen in the Yakima Basin are given in Appendixes B, C, and D, respectively.

The names and addresses of farmers were obtained from the various irrigation districts in the Yakima Basin. The farm questionnaire was sent to a random sample of 212 names drawn from the list. Thirty percent of the farmers returned completed questionnaires but only 41 were usable.

The names and addresses of sport fishermen in the Yakima Basin were obtained from the Washington State Department of Game, Yakima Office, and various sport fishing groups in the lower Yakima Basin. Attempts to obtain the names and addresses of Yakima Indian fishermen were futile. A random sample of 232 names was drawn from the list compiled. The questionnaire shown in Appendix D was sent to each of the 232 fishermen. Forty percent of the sport fishermen returned completed questionnaires of which 38 were ultimately used.

Obtaining the names and addresses of recreationists proved to be difficult because the members of this group are not as easily identifiable as fishermen, who are all required to buy fishing permits, or farmers who obtain their irrigation water under contract with irrigation districts.

Recreationists' names were picked at random from the 1979 telephone directories of the towns in the Yakima Basin. To this list a few names of the sport fishermen were added. Finally, the questionnaire given in Appendix C was sent to each of these 207 names picked at random. Thirty-six percent of the recreationists completed and returned the questionnaire of which 39 were used.

Respondents (farmers, recreationists, and fishermen) were furnished with definitions of five water quality levels: perfect, very good, good, poor, and very poor. They were also given the numerical ranges of each quality level. Based on the definitions, individuals were asked to classify the quality of the Yakima River for their own uses. Based on the numerical ranges given for each quality level (e.g., good quality), respondents were also asked to assign a single numerical value within the given range to the quality of the Yakima River for their specific water use. Answers to these two questions determined the water quality of the Yakima River for these three water uses descriptively and numerically. These definitions for agricultural, recreational, and fishing uses were given in Tables 4, 5, and 6, respectively.

Table 7 summarizes the survey responses of farmers, recreationists, and fishermen concerning current water quality of the lower Yakima River. A large majority of the farmers classified the quality of irrigation water diverted from the Yakima River as being good or better, while a large majority of the fishermen classfied the water quality of the Yakima River as being of poor or worse quality (Table 7).

TABLE 7. PERCENTAGE OF WATER USERS CLASSIFYING THE CURRENT QUALITY OF THE YAKIMA RIVER INTO ONE OF FIVE DIFFERENT QUALITY LEVELS

Designation	Percentage of farmers[a]		Percentage of recreationists[b]	Percentage of fishermen[c]
	(Worst month)	(Season)	(Seasonal average)	(Seasonal average)
Very poor	2	0	8	16
Poor	22	10	31	58
Good	52	39	54	21
Very good	17	44	8	5
Perfect	7	7	0	0

[a] Based on 41 responses.

[b] Based on 39 responses.

[c] Based on 38 responses.

Farmers, recreationists, and fishermen were also asked if the quality of the lower Yakima needs improving. Their responses are summarized in Table 8. It is clear from Table 8 that 90% of the fishermen and 84% of the recreationists would like to see the quality of the Yakima River improved, while only 29% of the farmers surveyed want water quality improvements.

Table 8 also gives the average numerical rating of the perceived current quality of the Yakima River. For example, fishermen assigned a water quality index of 50 to the Yakima River, while recreationists assigned a water quality index of 57 to the Yakima River. Farmer, on the other hand, assigned a water quality index of 65 to their irrigation water coming from the Yakima River, during the worst quality month.

TABLE 8. PERCENTAGE OF FARMERS, RECREATIONISTS, AND FISHERMEN WHO FEEL THE QUALITY OF THE YAKIMA RIVER NEEDS IMPROVEMENT

Water user group	Percentage	Current Water quality index[a]
Farmers[b]	29	65[e]
Recreationists[c]	84	57
Fishermen[d]	90	50

[a] Current water quality index is the average water quality index ratings obtained from the respondents. It is computed as a simple mean for each water user group.

[b] Based on 34 responses.

[c] Based on 58 responses.

[d] Based on 72 responses.

[e] This average water quality index is for the worst month. The average water quality index for the rest of the irrigation season was 79.

Respondents to the three questionnaires were asked to reveal their average annual willingness to pay for improving the quality of the lower Yakima from its current quality level to higher quality levels. Their responses are summarized in Table 9. The annual willingness to pay figures for farmers are dollar values per irrigated hectare of irrigated farmland. For recreationists and fishermen, the average annual willingness to pay figures in Table 9 are values per household. There were 3.3 persons per respondent household participating in recreation, and there were 2.3 persons per respondent household participating in fishing. For example, in Table 9, to change the quality of the lower Yakima River from poor to good, each

TABLE 9. RESPONDENTS' ANNUAL WILLINGNESS TO PAY FOR WATER QUALITY IMPROVEMENTS IN THE YAKIMA RIVER

Water quality level changes	Annual willingness to pay in dollars				
	Farmers[a]			Recreationists[b]	Fishermen[c]
	Ditch	Sprinkler	Head		
Very poor to poor				$ 2.42	$ 0.44
Poor to good				11.00	9.20
Good to very good	$7.66[d]	$12.94[d]	$4.94	52.79	27.08
Very good to perfect				35.95	35.95

[a] Farmers' willingness to pay is based on average costs incurred per hectare of irrigated farmland for ditch maintenance, sprinkler maintenance, and weed control.

[b] Based on 33 responses, and willingness to pay values shown are per household consisting of 3.3 persons on the average.

[c] Based on 22 responses, and willingness to pay values shown are per household consisting of 2.3 persons on the average.

[d] Average costs per hectare of irrigated farmland.

fisherman household in the sample was willing to pay $9.20 while for the same quality improvement each recreationist household was willing to pay $11.00 annually. Table 9 should be viewed with caution. First, extreme responses were excluded in computing the average willingness to pay reported in Table 9. Specifically, extremely high values and zero responses were excluded. Second, the sample does not include members of the Yakima Indian Tribe who use the Yakima River for both subsistence and ritualistic fishing. Clearly, there is a possibility that water quality improvements in the Yakima River may have option value to the Indians of the region. Other residents may also have option value for a better water quality in the Yakima River. In addition, it is possible that Indians and others attach value to passing on a better water quality to the next generation. The willingness to pay reported in Table 9 fails to incorporate these values.

Table 9 does not give the average willingness to pay for farmers. This is because most of the willingness to pay responses were incomplete. However, a better response was obtained from farmers on costs incurred in fighting bad water quality. Three kinds of costs were considered. These were cost of removing sediment from irrigation ditches, cost of sediment damage to sprinkler systems,and the cost of controlling weeds and moss growing along irrigation supply ditches.

The cost of removing sediment from irrigation ditches ranged from $0.12 to $22.23 per irrigated hectare per year with an average cost of $7.66. The increased wear to sprinkler systems ranged from $1.75 to $24.70 per irrigated hectare with an average cost of $12.94. The questionnaire sent to farmers did not include a question on the cost incurred for controlling weed and moss growing on the banks of irrigation ditches. Instead this information was obtained from irrigation districts and ditch companies. The average cost for controlling weed and moss growth was estimated to be $4.94 per irrigated hectare per year. It was further assumed that these costs incurred by agriculture were equivalent to the willingness to pay for raising the irrigation water quality to the highest level.

A relatively small effort was devoted to obtaining user perceptions of water quality in the Yakima River and their willingness to pay for improvements in the water quality. This was because the major objective of the study was to derive and demonstrate a method for relating changes in water quality parameters to changes in the value to individual users. It is recognized that measuring willingness to pay for a common resource good is a major task in itself and should occupy much greater resources in an actual evalution than were available in this study.

Derivations of Willingness To Pay Functions

The information on willingness to pay presented in Table 9 and the average per hectare of irrigated farmland cost information provided in the preceding paragraph can best be utilized by deriving a continuous willingness to pay function within each quality level (e.g., good quality). This need is apparent because Table 9 indicated that each fisherman household is willing to pay \$9.20 to change the water quality from poor to good quality. The problem however, is that the value of slight or modest changes in water quality is not apparent. To avoid such problems the willingness to pay function within each quality level was linearized for each water use. A function of the form

$$P_k = b_0 + b_1 Q_k \quad (K_1 \leq Q_k < K_2) \tag{6.21}$$

was constructed for a specified range of Q_k where K_1 and K_2 are positive real numbers. In Equation 6.21, P_k stands for the average willingness to pay for use type K, Q_k is the water quality index for use type K, b_0 is the intercept, and b_1 is the slope coefficient.

The approach used to derive the willingness to pay function will be demonstrated using the willingness to pay values for recreation given in Table 9. The average recreationist is willing to pay \$2.44 to change the water quality from very poor to poor. Very poor water quality has an index value ranging from 0 to 29 and poor water quality begins when the water quality index is 30 (Table 5). Thus, the average recreationist is willing to pay \$0.08 for a unit change in the water quality index when the water quality index for recreation (Q_2) ranges from 0 to 30 (\$2.44 ÷ 30 = \$0.08). Thus, the willingness to pay function for recreational water use when the water quality index ranges between 0 and 30 becomes

$$P_2 = 0.08\ Q_2 \quad (0 \leq Q_2 < 30) \tag{6.22}$$

A similar procedure was followed in establishing the willingness to pay equation shown in 6.23 for recreation and 6.24 for fishing.

$$P_2 = \begin{cases} -0.08\ Q_2 & (0 \leq Q_2 < 30) \\ -8.96 + 0.38\ Q_2 & (30 \leq Q_2 < 60) \\ -113.28 + 2.11\ Q_2 & (60 \leq Q_2 < 85) \\ -154.63 + 2.57\ Q_2 & (85 \leq Q_2 \leq 100) \end{cases} \tag{6.23}$$

$$P_3 = \begin{cases} 0.015\ Q_3 & (0 \leq Q_3 < 30) \\ -9.08 + 0.32\ Q_3 & (30 \leq Q_3 < 60) \\ -55.35 + 1.08\ Q_3 & (60 \leq Q_3 < 85) \\ -129.63 + 1.93\ Q_3 & (85 \leq Q_3 \leq 100) \end{cases} \tag{6.24}$$

To derive the willingness to pay functions for agricultural use, it was assumed that the benefit of water quality improvement to a farmer is at least equal to the cost the farmer avoids by having an improved quality of irrigation water. The average cost for removing sediment from irrigation ditches was \$7.66 per hectare of irrigated farmland per year; therefore, the willingness to pay function (the "avoided cost") is

$$P_d = \begin{cases} 7.66 - 0.1021\ I_{11} & (0 < I_{11} \leq 75) \\ 0 & (I_{11} > 75) \end{cases} \tag{6.25}$$

where P_d is the willingness to pay for reducing the level of sediment in irrigation ditches per hectare of irrigated farmland and I_{11} is the water quality index with respect to the water quality parameter X_1 (farm delviery sediment concentration).

The average annual cost incurred for maintenance and repair on irrigation systems due to sediment in irrigation water was shown to be \$12.94 per hectare of irrigated farmland. It was assumed that \$12.94 per hectare of irrigated farmland per year would measure the benefits of improving the sediment water quality index from present levels to a sediment quality index (I_{11}) of 90. Thus, the willingness to pay to decrease the amount of sediment in irrigation water to avoid increased sprinkler maintenance costs is given by

$$P_s = \begin{cases} 12.94 - 0.14377\ I_{11} & (0 < I_{11} \leq 90) \\ 0 & (I_{11} > 90) \end{cases} \tag{6.26}$$

where P_s is the willingness to pay and I_{11} is the water quality index due to the water quality parameter X_1.

Another cost item incurred by farmers is expense for control of weeds and moss in irrigation canals. This cost was shown to be \$4.94 per hectare of irrigated farmland per year. It was assumed that this cost would apply linearly up to a water quality index (I_{14}) of 85. The benefits of a water quality index (I_{14}) higher than 85 is 0. Based on this, the willingness to pay to reduce the growth of weeds and moss in irrigation ditches (P_w) from sediment causes becomes

$$P_w = \begin{cases} 4.94 - 0.05812\ I_{14} & (0 \leq I_{14} \leq 85) \\ 0 & (I_{14} > 85) \end{cases} \tag{6.27}$$

where P_w is the willingness to pay to reduce the growth of weeds in irrigation ditches and I_{14} is the water quality index.

Derivation of Minimum Acceptable Compensation

The questionnaires sent to farmers, recreationists, and fishermen also asked how much each respondent household was willing to accept as a compensation if the quality of the Yakima River was to be reduced in quality from its current level to lower quality levels. Table 10 gives

TABLE 10. RESPONDENTS' ANNUAL MINIMUM ACCEPTABLE COMPENSATION FOR REDUCING WATER QUALITY IN THE YAKIMA RIVER

Water quality	Minimum acceptable compensation per year				
	Farmers[a]			Recreationists[b]	Fishermen[c]
	Ditch	Sprinkler	Weed		
Perfect to very good				$161.10	$14.10
Very good to good				223.40	13.10
Good to poor	$12.92[d]	$18.97[d]	$9.88[d]	666.60	64.60
Poor to very poor				503.30	57.50

[a] The minimum acceptable compensation that farmers require is based on average cost incurred per hectare of irrigated farmland by 50% of the farmers who had average per hectare costs greater than the median average cost. See text for details.

[b] The minimum acceptable compensation that recreationists require is obtained after deleting extremely high and zero responses.

[c] The minimum acceptable compensation that fishermen require is obtained after deleting extremely high and zero responses.

[d] Average costs per hectare of irrigated farmland.

the minimum acceptable compensation for water quality reductions from current quality levels.

Table 10 shows that each recreation household is willing to accept as compensation $666.60 for reducing water quality from good quality to poor quality. Each fisherman household requires $64.60 for a reduction in water quality from good to poor to maintain the level of satisfaction derived prior to quality degradation.

The information in Table 10 was utilized for deriving a continuous function showing average minimum acceptable compensation (C_k) as a function of aggregate water quality index (Q_k) within each quality level for both recreation and fishing. The same procedure used to derive the willingness to pay functions in the preceding section was used to derive the minimum acceptable compensation functions for recreation and fishing. Equation 6.28 estimates the minimum acceptable compensation (C_2) for recreation while Equation 6.29 estimates the minimum compensation (C_3) for fishing.

$$C_2 = \begin{array}{ll} 1554.40 - 17.36\ Q_2 & (0 \leq Q_2 < 30) \\ 1740.69 - 22.99\ Q_2 & (30 \leq d_2 < 60) \\ 920.66 - 8.94\ Q_2 & (60 \leq Q_2 < 85) \\ 1150.71 - 11.51\ Q_2 & (85 \leq d_2 \leq 100) \end{array} \qquad (6.28)$$

$$C_3 = \begin{array}{ll} 149.30 - 1.98\ Q_3 & (0 \leq Q_2 < 30) \\ 158.63 - 2.23\ Q_3 & (30 \leq Q_3 < 60) \\ 58.64 - 0.52\ Q_3 & (60 \leq Q_3 < 85) \\ 100.71 - 1.01\ Q_3 & (85 \leq Q_3 \leq 100) \end{array} \qquad (6.29)$$

To derive the minimum acceptable compensation functions for agriculture use, it was assumed that the necessary compensation was equivalent to the maximum average cost incurred. The procedure followed was to arrange the per hectare costs for ditch maintenance and sprinkler system maintenance obtained from farmers in ascending order of magnitude and divide these costs into two groups containing an equal number of responses. The average per hectare costs for the above average cost was assumed to be minimum acceptable compensation required by farmers for water quality degradation. This is an admittedly very crude method for estimating compensation requirements for farmers. This procedure resulted in estimated costs to maintain ditches of $12.92 per hectare per year and a cost per hectare for maintaining sprinkler irrigation sytems of $18.97 per year. Finally, it was assumed that the minimum cost incurred per hectare per year to control weed and moss growth to be $9.88 annually. This is twice the actual per hectare cost incurred by farmers.

The estimated compensation functions for ditch maintenance, sprinkler maintenance and weed control are shown by Equations 6.30, 6.31, and 6.32, respectively.

$$C_d = \begin{cases} 12.92 - 0.1722\, I_{11} & (0 < I_{11} \leq 75) \\ 0 & (I_{11} > 75) \end{cases} \tag{6.30}$$

$$C_s = \begin{cases} 18.97 - 0.2108\, I_{11} & (0 < I_{11} \leq 90) \\ 0 & (I_{11} > 90) \end{cases} \tag{6.31}$$

$$C_w = \begin{cases} 9.88 - 0.1162\, I_{14} & (0 < I_{14} \leq 35) \\ 0 & (I_{14} > 85) \end{cases} \tag{6.32}$$

Number of Beneficiaries

The average willingness to pay and compensation functions derived in the preceding two sections gave the average respondent's valuation of water quality changes. The total social value of water quality improvement is shown by the following equation

$$B = \sum_{k=1}^{3} \sum_{i=1}^{n} \Delta P_{ik} \tag{6.33}$$

where B is the total social value (total benefit) and ΔP_{ik} is the value of the change to individual i in water use k, where n is the number of individuals (or acres) relevant to use k. Similarly the aggregate compensation necessary for water quality degradation would be derived by the following equation

$$D = \sum_{k=1}^{k} \sum_{i=1}^{n} \Delta C_{ik} \tag{6.33}$$

For the purposes of this study, the following assumptions are made about the number of beneficiaries in each type of water use. In the Yakima Basin, there are about 200,000 hectares (500,000 acres) of irrigated farmland. Sediment is a major problem on farms in the Roza and Sunnyside irrigation divisions where the combined irrigated farmland is about 50,000 hectares (125,000 acres). This was the area assumed to be affected by sediment control problems. It is also assumed that the number of hectares of irrigated farmland in the lower Yakima requiring maintenance of sprinkler irrigation systems is 18,000 hectares (45,000 acres) and that 18,400 hectares (46,000 acres) require weed and moss control.

Information obtained from the Washington State Department of Game, Yakima Office,[8] indicated that there are about 74,280 fishermen in the three counties (Kittitas, Yakima, and Benton) that make up the Yakima Basin. Of this total 40,856 are licensed fishermen and the remainder are juvenile or free fishing license holders.

There are about 250,000 people in the Yakima Basin and according to the Washington State Department of Game, Yakima Office, 30% of the basin's population fish. From the mail questionnaires sent to fishermen, it was found that there were 2.3 persons per respondent household. Hence, the number of households that fish was estimated to be 32,607.[9] It will be assumed that the number of fishermen benefiting from water quality improvement is 32,600. It will also be assumed that the willingness to pay values obtained and compensation values reported are for a household.

According to the Pacific Northwest River Basin Commission (1977), residents of Yakima Country spend 651,000 man days in swimming. The mail indicated that the average recreationist spends one day during each visit; makes six visits to the Yakima River annually; and there are 3.3 persons participating in outdoor water-oriented recreation per household. The number of households that participate in water recreation in the Yakima River based on the three assumptions is 32,879[10] Hence the number of households participating in water recreation in the Yakima River is assumed to be 32,900.

Marginal Utility of Money

In this study it was assumed that the marginal utility of money is the same for all beneficiaries. It is to be admitted at the outset that the assumption of the constant marginal utility of money does not have much support, both from policymakers and from real world observations. However, a consensus has not emerged as to how benefits accruing to people with different income levels are to be weighted even though there seems to be agreement among many economists that benefits accruing to lower income people might be given more weight.[11] Haveman (1965) used the U.S. federal income tax tables to derive the weights that the federal government (the

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[8] Telephone conversation with Oliver Wendell, Department of Game, Yakima Office, November 26, 1980.

[9] $$32607 = \frac{250{,}000\ (0.3)}{2.3}$$

[10] $$32789 = \frac{651{,}000}{6(3.3)}$$

[11] Others have argued that distributional issues should be left out of project evaluations since there are a wide variety of more efficient policies (macroeconomic policies, e.g., income transfer) available to the government to achieve an acceptable distribution of income.

U.S. Congress) attaches to the income accruing to people with different income levels. Freeman (1972) has suggested basing the benefit estimates on the valuation (willingness to pay or required compensation) of persons with incomes close to the mean. The reason given is that this approach deflates the values of benefits going to high income groups as their willingness to pay or required compensation is high and inflates the values of benefits going to low-income groups (as their willingness to pay or required compensation is low).

In any case the assumption of the quality of the marginal utility of money for all beneficiaries is necessary to aggregate the benefits accruing to people with different income levels.

THE COMPUTER PROGRAM

A computer program linking the water quality and economic submodels was written to measure the benefits of water quality changes. The full text of the computer program is given in Appendix E.

The computer program was written in standard FORTRAN IV. The program gives a detailed and organized sequence of instructions to be carried out in determining benefits of water quality improvements. The computer program given in Appendix E provides two measures of benefit: willingness to pay for water quality improvements and minimum required compensation for reductions in water quality.

The program data requires data input on water quality parameters and number of beneficiaries for each of the water uses. In addition, one also has to specify the water quality variable to be changed, the magnitude of the change, and the number of times the change in the water quality parameter is to be made.

The computer program determines the following items:

1. Average willingness to pay per respondent, associated with a given water quality index.
2. Average minimum required compensation per respondent, associated with a given water quality index.
3. Additional willingness to pay associated with a change in water quality from one numerical quality index level to another.
4. Additional minimum required compensation associated with a change from one numerical quality index level to another.
5. Total additional willingness to pay from numerical quality index change.
6. Total additional minimum required compensation from numerical quality index change.

SECTION 7

APPLICATION OF THE EMPIRICAL MODEL

This section demonstrates the empirical model developed to estimate the economic benefits from water quality improvement policies in the Yakima River Basin. Three primary water quality improvement policies (flow augmentation, reduced nitrate levels, and reduced sediment and turbidity levels) are analyzed using the empirical model.

First a short demonstration of how the empirical model works is given. Second, a description of water quality improvement policies selected for analysis is given. Then the benefits of each water quality improvement policy are estimated and compared to the benchmark water quality scenario. Finally, social benefits and costs of selected water quality improvement policies are compared.

HOW THE EMPIRICAL MODEL WORKS

The empirical water quality submodel calculates the water quality indices (I_{kj}) for each water use with respect to the relevant water quality parameter. Once the water quality indices have been calculated, the limiting water quality parameter for each use is determined by employing the minimum operator function. The general process is demonstrated below.

Table 11 gives the current water quality data for the lower Yakima River at Kiona. Substituting the water quality data in Table 1 into Equations 6.5 through 6.18, one obtains the water quality indices for each water use and water quality parameter. Table 12 gives the current water quality indices (I_{kj}) for the three water uses derived in this fashion. For example, in Table 12, the agricultural water use quality index for sediment concentration in irrigation water (X_1) is 72, while the recreational water quality index for termperature (X_4) is 81.

The aggregate watter quality index (Q_k) for each water use is determined by the lowest water quality index (I_{kj}). Hence, in Table 12, ditch maintenance and sprinkler maintenance are both limited by the level of sediment in irrigation water (X_1). Recreational water use is limited by bacteria count (X_2) and turbidity (X_8) simultaneiously. Fishing water use is similarly limited by high bacteria count (X_2). Hence, for each of these uses, additional benefits would be realized only by affecting those water quality parameters that are limiting.

TABLE 11. CURRENT WATER QUALITY DATA FOR AVERAGE STREAM FLOW CONDITIONS IN THE LOWER YAKIMA RIVER[a] FOR SELECTED WATER QUALITY VARIABLES

Water quality variable	Unit	Measured level
Farm delivery sediment concentration (X_1)	mg/l	170
Fecal bacteria count (X_2)	median no. per 100 ml	174[b]
Dissolved oxygen (X_3)	mg/l	7.7
Water temperature (X_4)	°C	21.8
Nitrate nitrogen (X_5)	mg/l	0.89
Phosphate phosphorus (X_6)	mg/l	0.12
Low stream flow (X_7)	CMS	37.189
Turbidity (X_8)	JTU	17.00[c]

[a] All measurements are at Kiona except for X_1 which was measured on farms in the lower Sunnyside Valley Irrigation District.

[b] 1975 data obtained from U.S. Army Corps of Engineers, Seattle District.

[c] 1974 data obtained from U.S. Army Corps of Engineers, Seattle District, 1978, Yakima Valley Regional Water Management Study, Vol. 2, Seattle, WA.

All other data obtained from CH_2M-Hill, 1975b, Characterization of Present Water Quality Conditions in the Yakima Basin, Technical Bulletin No. 10, Olympia.

TABLE 12. WATER USE QUALITY INDICES FOR CURRENT WATER QUALITY CONDITIONS IN THE LOWER YAKIMA RIVER

Water quality variable	Water use quality indices				
	Agricultural			Recreational	Fishing
	Ditch	Sprinkler	Weed		
X_1	72	72	N	N	N
X_2	N[a]	N	N	54	54
X_3	N	N	N	N	75
X_4	N	N	59	81	69
X_5	N	N	N	65	65
X_6	N	N	N	65	65
X_7	N	N	59	81	69
X_8	N	N	N	54	70

[a] N means not applicable.

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Suppose the high bacteria count (X_2) is reduced to an acceptable level and is no longer limiting to fishing. Fishermen will realize additional benefits from reducing bacteria count until the aggregate water quality index for fishing (Q_3) reaches 65, where nitrates (X_5) and phosphates (X_6) become limiting. At this point, fishermen would realize additional benefits from a water quality improvement policy that reduces the levels of all these parameters simultaneously to an aggregate water quality index (Q_3) of 69 where water temperature (X_4) becomes the limiting factor.

Using similar arguments one can also demonstrate that recreationists would receive additional benefits by improving water quality parameters according to the following sequence: instream sediment, bacteria, nitrate, phosphate, and water temperature. For agricultural use no sequencing problem arises because reducing either the level of sediment in irrigation (X_1) or reducing water temperature (X_4) yields additional benefits to irrigators in the form of reduced maintenance costs.

Fishing is now used to demonstrate the procedure for estimating benefits using the willingness to pay measure. Initially, fishing is limited by bacteria. The benefits per household that are associated with reduced levels of bacteria, while the level of other water quality parameters remain at their current level (Table 11), are given by the curve ABC in Figure 15. This curve is derived by using Equation 6.24 showing that willingness to pay per household increases from zero to $6.65 per year. To reduce the concentration of nitrates and phosphates until they are no longer limiting fishing, each household is willing to pay $4.32 additional per year. This is shown by the segment BDE in Fig. 15. Segment BDE is derived using Equation 6.24 to estimate the annual willingness to pay to increase the aggregated water quality index from 65 to 69.

Similar logic was used to derive the recreational benefits curves given in Fig. 16 and the agricultural benefits curves given in Fig. 17. Figure 17 gives farm operators' willingness to pay per irrigated hectare of farmland to improve irrigation water quality from its current level to avoid incurring additional expenses for sprinkler maintenance, weed control, and ditch maintenance. From Fig. 17, the maximum that each farm operator is willing to pay per hectare of irrigated farmland for improving irrigation water quality to a level of perfection is $4.41 per year.

Figure 18 presents the aggregate benefits accruing to each of the three water uses from sequentially relaxing limiting water quality parameters for each use. The aggregate benefit curves for each use in Fig. 18 are obtained by multiplying the average benefit curves in Fig. 15, 16, and 17 by the number of beneficiaries in each use. In Fig 18, the aggregate social benefit curve ABCDE is obtained by vertically summing the aggregate benefits accruing to each use at given aggregate water quality index levels. Increasing the water quality to a level of perfection yields an aggregate willingness to pay of $2.5 million annually.

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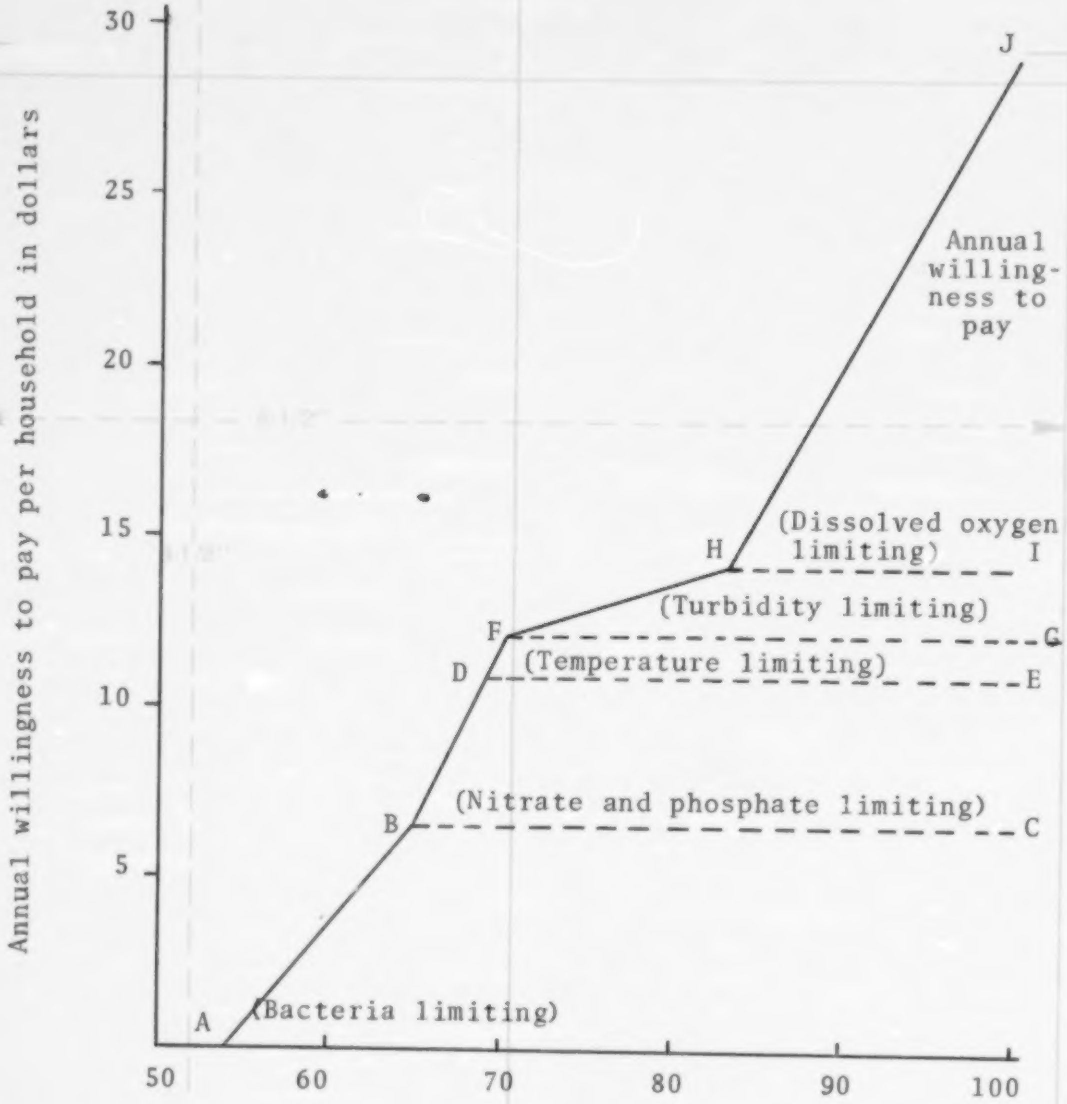

Figure 15. Annual fishing benefits per household from sequentially improving limiting parameters.

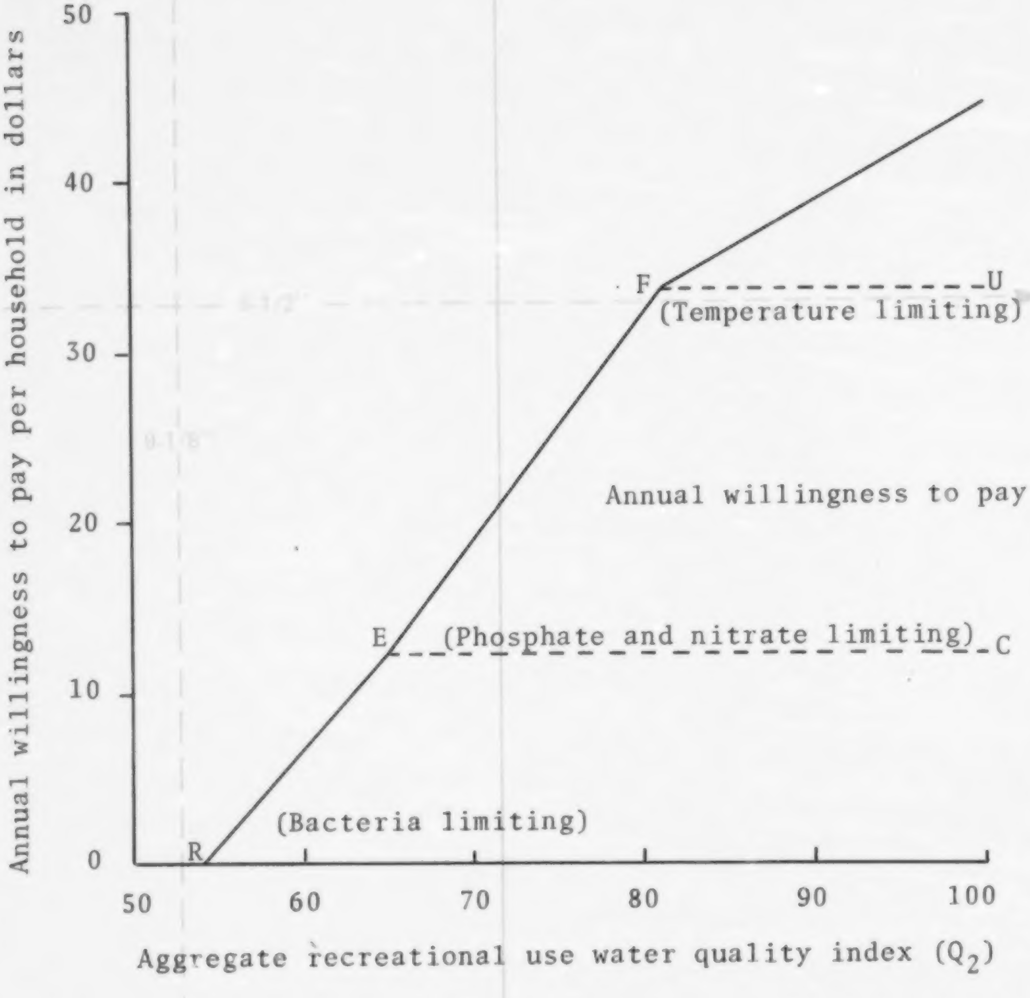

Figure 16. Annual willingness to pay per household for sequentially improving current water quality for recreational use.

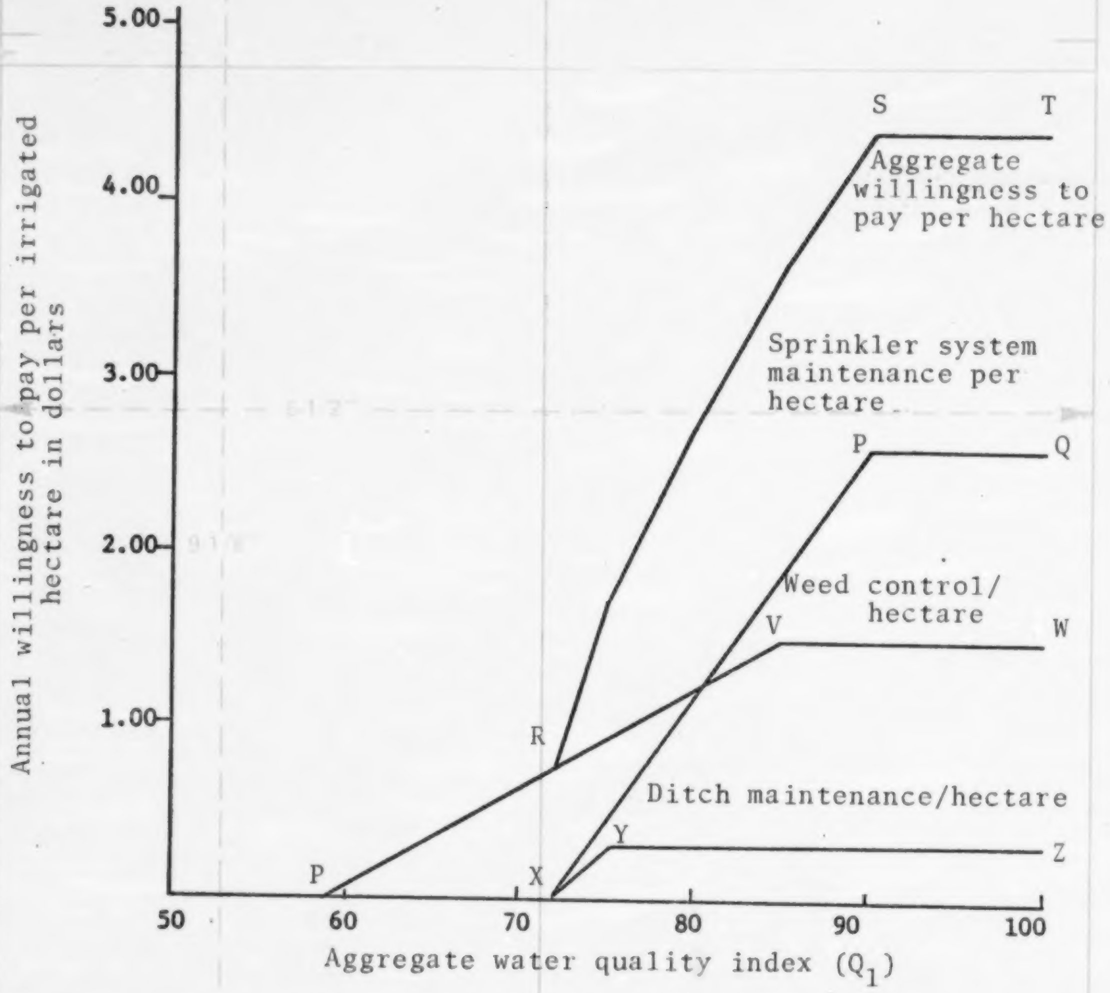

Figure 17. Annual willingness to pay per irrigated hectare to improve water quality from its current quality level.

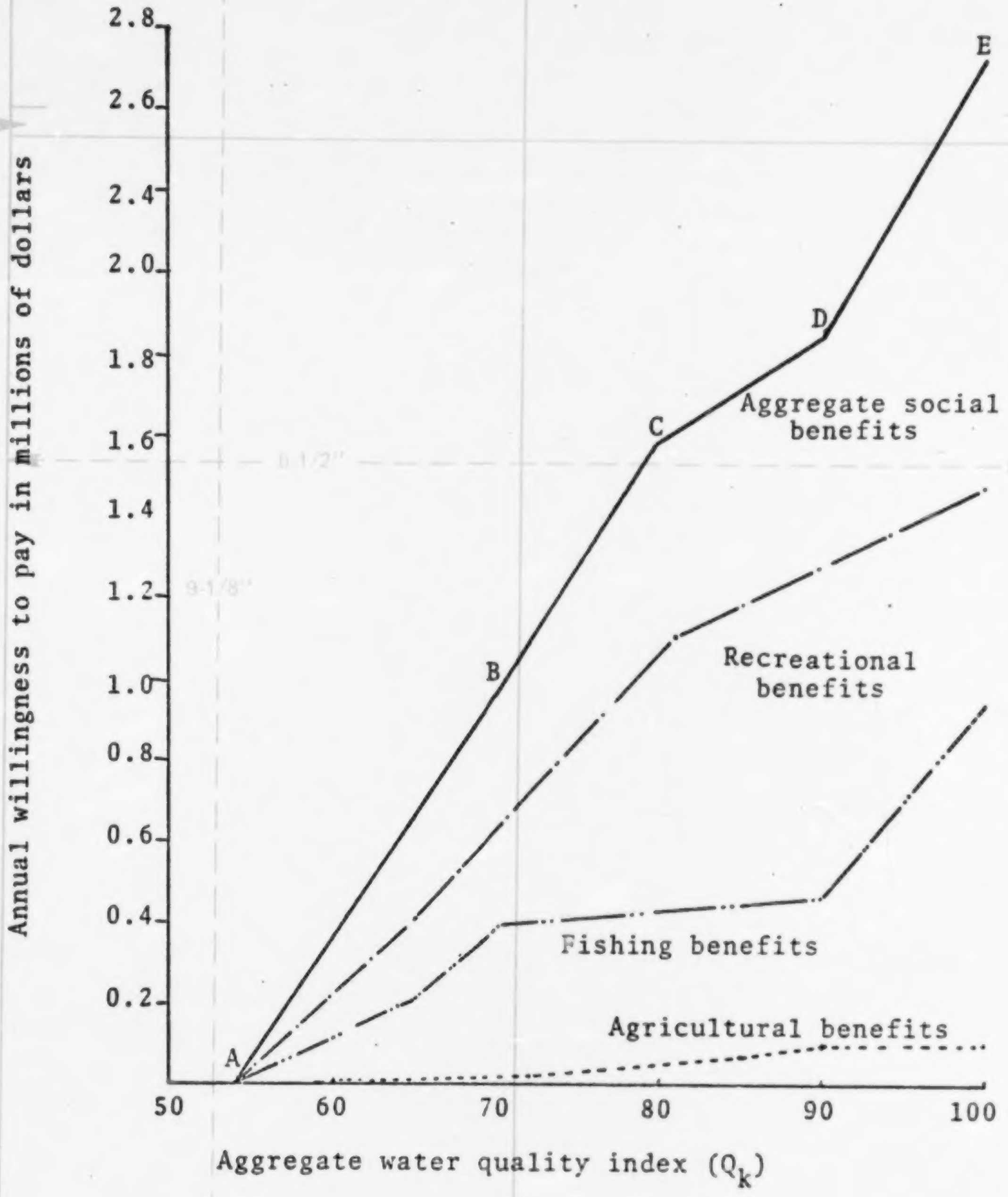

Figure 18. Annual benefits from sequential water quality improvement.

WATER QUALITY IMPROVEMENT POLICIES

Significant water quality problems arise on the mainstem of the Yakima River and its tributaries below Sunnyside Dam (see Fig. 14) during the low stream flow summer months. Much of the stream flow in the lower Yakima River during the summer months consists of irrigation return flows, which carry sediment, plant nutrients (mainly nitrogen and phosphorus fertilizers), and dissolved salts to the Yakima River.

Water quality in the lower Yakima River can be mitigated in a number of ways. However, this study is concerned only with the valuation of the economic benefits of water quality improvement, regardless of the method or source of improvement.

This study analyzes the benefits of three major water quality improvement policies:

1. Stream flow augmentation.

2. Reduced sediment and turbidity levels.

3. Reduced nitrate levels.

Stream augmentation and reduced nitrate levels are chosen for analysis because cost estimates exist for these two policies. The selection of reduced turbidity and sediment is to further demonstrate the application of the empirical model. Four water quality states or scenarios are considered.

Scenario I

Scenario I refers to the prevailing water quality conditions in the lower Yakima River and represents the benchmark water quality condition. It is the base from which all water quality improvement is to be measured. The current water quality data for the lower Yakima River was given in Table 11.

In Scenario I, no water quality improvement or degradation takes place. As a result, there are no benefit measurements.

Scenario II

Scenario II refers to the water quality state that would exist with stream flow augmentation. Increasing stream flow from its current level has a dilution effect upon the level of other water quality parameters present in the river. Increases in stream flows would most likely be achieved by providing additional storage upstream or by changes in agricultural production practices that promote inefficient water use on the farms. Benefits will be determined for four selected stream flow levels, 37 (the current stream flow), 74, 111, and 148 CMS.

Before benefits can be determined, the dilution effect needs to be determined for each water quality parameter. This study assumes that the new level of most water quality parameters is proportional to the increase in stream flow. Therefore,

$$d = \frac{\hat{X}_7}{X_7} \tag{7.1}$$

and

$$\hat{X}_j = \frac{X_j}{d} \tag{7.2}$$

where

X_7 = initial level of stream flow in CMS

$\hat{X}_7$ = new level of stream flow in CMS

X_j = initial level of parameter X_j associated with a stream flow of X_7

X_j = new level of parameter X_j associated with new stream flow level of $\hat{X}_7$

d = dilution coefficient

A different procedure was used to estimate new levels for temperature (X_4) and dissolved oxygen (X_3) because of physical relationships that exist between flow, temperature, and dissolved oxygen. Equations 6.7 and 6.16 were used to calculate water quality levels for X_3 and X_4.

Table 13 gives the water quality parameters in columns 2, 3, and 4 and indices (I_{kj}) in columns 5 to 13 associated with flow levels of 74, 111, and 148 CMS. Columns 5, 6, and 7 give the water quality indices for agricultural (I), recreational (R), and fishing (F) uses for the water quality data associated with flow level of 74 CMS. Similarly, columns 8, 9, and 10 give the water quality indices for agricultural, recreational, and fishing uses for water quality data associated with flow level of 111, while columns 11, 12, and 13 give the water quality indices associated with a flow level of 148 CMS.

Table 14 gives the benefits of increased stream flow. These three water quality levels were given in columns 2, 3, and 4 of Table 13. Column 2 of Table 14 shows that the aggregate water quality index for recreation (Q_2) increases from 54 to 76, as stream flow is increased from its current level of 37 to 74 CMS. Increasing stream flow from 37 to 74 CMS increases the annual willingness to pay for recreational use per household from zero to \$35.52, while increasing stream flow from 74 to 111 CMS increases willingness to pay by an additional \$16.88 per year.

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TABLE 13. LEVELS OF WATER QUALITY PARAMETERS AND INDICES ASSOCIATED WITH THREE NEW LEVELS OF STREAM FLOW (SCENARIO II)

Parameter	Water quality parameters			Water quality indices								
	A[a]	B	C				B			C		
				I[b]	R	F	I	R	F	I	R	F
X_1	170	170	170	72	N[c]	N	72	N	N	72	N	N
X_2	87	58	43.5	N	77	77	N	85	85	N	87	87
X_3	8.2	8.69	9.19	N	N	82	N	N	89	N	N	96
X_4	19.79	17.7	15.6	74	96	80	88	100	89	100	100	95
X_5	0.435	0.29	0.22	N	82	82	N	88	88	N	91	91
X_6	0.06	0.04	0.03	N	82	82	N	88	88	N	91	91
X_7	74	111	148	74	96	80	88	100	89	100	100	95
X_8	8.5	5.6	4.25	N	76	85	N	84	90	N	88	93

[a] A = water quality data associated with X_7 = 74; B = water quality data associated with X_7 = 111; C = water quality data associated with X_7 = 148.

[b] I, R, and F are water quality indices for irrigation, recreation, and fishing uses, respectively.

[c] N = not applicable.

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TABLE 14. AVERAGE ADDITIONAL ANNUAL BENEFITS FROM INCREASING STREAM FLOW TO THREE SELECTED FLOW LEVELS (SCENARIO II)

Water use	Water quality level A[a]			Water quality level B			Water quality level C		
	Aggregate water quality index change	Benefits		Aggregate water quality index change	Benefits		Aggregate water quality index change	Benefits	
		WTP(1)[b] ($)	COM(1) ($)		WTP(2)	COM(2)		WTP(3)	COM(3)
Agriculture									
ditch[c]	72 to 79	0.31	0.00	79 to 81	0.00	0.00	81 to 82	0.00	0.00
sprinkler[c]	72 to 79	1.01	0.00	79 to 81	.89	0.00	81 to 82	.64	0.00
weed[b]	59 to 74	0.87	1.74	74 to 88	0.10	0.00	88 to 100	0.00	0.00
Recreation[d]	54 to 76	35.52	258.01	76 to 84	16.88	71.52	84 to 87	5.00	20.36
Fishing[d]	54 to 77	18.53	19.61	77 to 85	7.69	3.74	85 to 87	3.86	2.02

[a] A, B, and C refer to the three levels of stream flow shown in Table 13.

[b] WTP = annual willingness to pay.

[c] Willingness to pay is per hectare of irrigated farmland.

[d] Willingness to pay is per household.

In Table 14, columns 4, 7, and 10 show how much the average beneficiary requires as a minimum compensation per year for reducing stream flow from 148 to 111, 111 to 74, and 74 to 37 CMS, respectively. Hence in Table 14, the average household requires a minimum compensation of $19.61 annually if stream flow were to be reduced from 74 to 37 CMS for fishing use. Note that the average household is willing to pay $18.53 annually to increase stream flow from 37 to 74 CMS for fishing use in Table 14.

Benefits of Scenario III

Scenario III represents a condition in which the level of sediments in irrigation water (X_1) and instream turbidity (X_8) are to be reduced. In addition, it is assumed that reducing the level of sediment also proportionately decreases the level of phosphates attached to soil particles. It is also believed that reducing the level of soil particles entering the Yakima River will reduce the level of pesticides and other pollutants such as coliform bacteria. Here, only the reduction in the concentration of phosphate is considered along with that of sediments in the determination of the benefits of water quality resulting from reduced sediment and turbidity levels in the Yakima River.

This study selected three sediment levels and three turbidity levels (labeled D, E, and G) for benefit measurement. The three sediment concentration levels in irrigation water (X_1) to be evaluated are 85, 57, and 42.5 mg/l. The three instream turbidity levels to be evaluated are 8.5, 5.6, and 4.25 JTU.

Table 15 gives the level of other water quality parameters in columns 2,3, and 4 and water quality indices (I_{kj}) for agricultural (I), recreational (R), and fishing (F) uses that are associated with the three reduced levels of X_1 and X_8. D, E, and G are water quality levels associated with the three reduced levels of X_1 and X_8. It is apparent that reductions in sediment and turbidity levels alone do little to affect the quality of water for any use. Agriculture is benefited a small amount but recreational and fishing uses are still limited by coliform bacteria levels.

Table 16 shows the benefits of the three reduced sediment and turbidity levels. In estimating the benefits given in Table 16, bacteria were assumed to be reduced to nonlimiting levels for recreation and fishing. Columns 2, 5, and 8 show changes in the aggregate water quality indices for agricultural, recreational, and fishing uses because of reduced sediment and turbidity levels--from their current levels to D, from D to E, and from E to G, respectively. Columns 3, 6, and 9 show the additional amount that individuals are willing to pay to have the levels of X_1 and X_8 reduced from their current levels to D, from D to E, and from E to G, respectively. Columns 4, 7, and 10 give the minimum annual compensation that the average beneficiary would require if the levels of X_1 and X_8 were to be increased from level D (column 2 of Table 15) to its initial level, from E to D, and from G to E, respectively.

TABLE 15. LEVELS OF WATER QUALITY VARIABLES AND INDICES ASSOCIATED WITH THREE REDUCED SEDIMENT AND TURBIDITY LEVELS (SCENARIO III)

Water quality parameter	Levels of water quality variables associated with each of the three sediment and turbidity levels			Water quality indices associated with each of the three water quality levels								
				D[a]			E			G		
	D	E	G	I	R	F	I	R	F	I	R	F
X_1	85	57	42.5	83	N[b]	N	85	N	N	87	N	N
X_2	174	174	174	N	54	53	N	54	54	N	54	54
X_3	7.7	7.7	7.7	N	N	75	N	N	75	N	N	75
X_4	21.8	21.8	21.8	59	81	69	59	81	69	59	81	69
X_5	0.87	0.87	0.87	N	65	65	N	65	65	N	65	65
X_6	0.06	0.04	0.03	N	82	82	N	88	88	N	91	91
X_7	37	37	37	59	81	69	59	81	69	59	81	69
X_8	8.5	5.6	4.25	N	76	85	N	84	90	N	88	95

[a] D, E, and G represent same as water quality in Table 11 except for changes in X_1, X_6, and X_8.

[b] N = not applicable.

TABLE 16. AVERAGE ADDITIONAL ANNUAL BENEFITS FROM REDUCING SEDIMENT AND TURBIDITY LEVELS (SCENARIO III)

	Water quality level D			Water quality level E			Water quality level F		
Water use	Aggregate water quality index change	Benefits		Aggregate water quality index change	Benefits		Aggregate water quality index change	Benefits	
		WTP($)	COM($)		WTP($)	COM($)		WTP($)	COM($)
Agriculture									
ditch[b]	72 to 79	0.31	0.52	79 to 81	0.00	0.00	81 to 82	0.00	0.00
sprinkler[b]	72 to 79	1.01	2.32	79 to 81	0.28	0.42	81 to 82	0.14	0.00
weed[c]	59 to 59	0.00	0.00	59 to 59	0.00	0.00	59 to 59	0.00	0.00
Recreation[c]	54 to 65	12.31	158.98	65 to 65	0.00	0.00	65 to 65	0.00	0.00
Fishing[c]	54 to 65	6.65	13.37	65 to 65	0.00	0.00	65 to 65	0.00	0.00

[a] WTP = annual willingness to pay to reduce sediment and turbidity, COM = minimum acceptable compensation for increasing sediment and turbidity.

[b] Willingness to pay and compensation per hectare of irrigated farmland.

[c] Willingness to pay and compensation per household.

Scenario IV

Scenario IV refers to a water quality condition in which the level of nitrates in the Yakima River are reduced from current levels until they no longer limit water use. The current level of nitrates in the lower Yakima River is given in Table 11. Reducing the level of nitrates in the lower Yakima River from current levels will benefit only recreation and fishing uses since agriculture is assumed to be unaffected by nitrate levels in irrigation water.

In estimating the benefits from reducing the concentration of nitrates in the lower Yakima River it is assumed that both bacteria count (X_2) and phosphates (X_6) levels have been reduced to acceptable levels. Otherwise, no benefits will be realized from reducing the concentration of nitrates from current levels.

For Scenario IV, the water quality data and water quality indices associated with different water quality levels are not presented in a table. The reason for this is that all the other water quality parameters remain the same as in Table 11. The only parameter that changes is nitrate (X_5). Also, the water quality indices for the other parameters other than nitrates remain the same as in Table 12.

Figure 19 shows estimated benefits that the average household participating in recreation and fishing might realize from reduced concentration of nitrates in the Yakima River. The segment ACD in Fig. 19 shows the benefits that the average fishing household would realize from reducing the concentration of nitrates from its current level. The average household participating in fishing is willing to pay $4.32 per year to decrease the concentration of nitrates from its current level of 0.87 mg/l until it is no longer limiting water use. Once the concentration of nitrates is reduced from 0.87 mg/l (point A in Fig. 19) to 0.77 mg/l (point B), reductions in the level of nitrates would not yield additonal benefits to fishermen. This is because, at this point water temperature limits fishing use and reducing nitrate levels would not help. Equation 6.26 was used to estimate the benefits that accrue to the average household participating in fishing.

In Fig. 19, the average household participating in recreation is willing to pay $33.76 per year to reduce the concentration of nitrates from 0.87 mg/l to 0.47 mg/l, segment AEF. Once the concentration of nitrates is reduced to 0.57 mg/, additional benefits cannot be realized by recreationists. At this point, low stream flow becomes a limiting factor.

The required compensation measures for changing nitrate levels were not calculated. The interested reader may use equations 6.28 and 6.29 to estimate the minimum compensation that the average household participating in recreation and fishing demands, if the level of nitrates were to be increased to 0.87 mg/l.

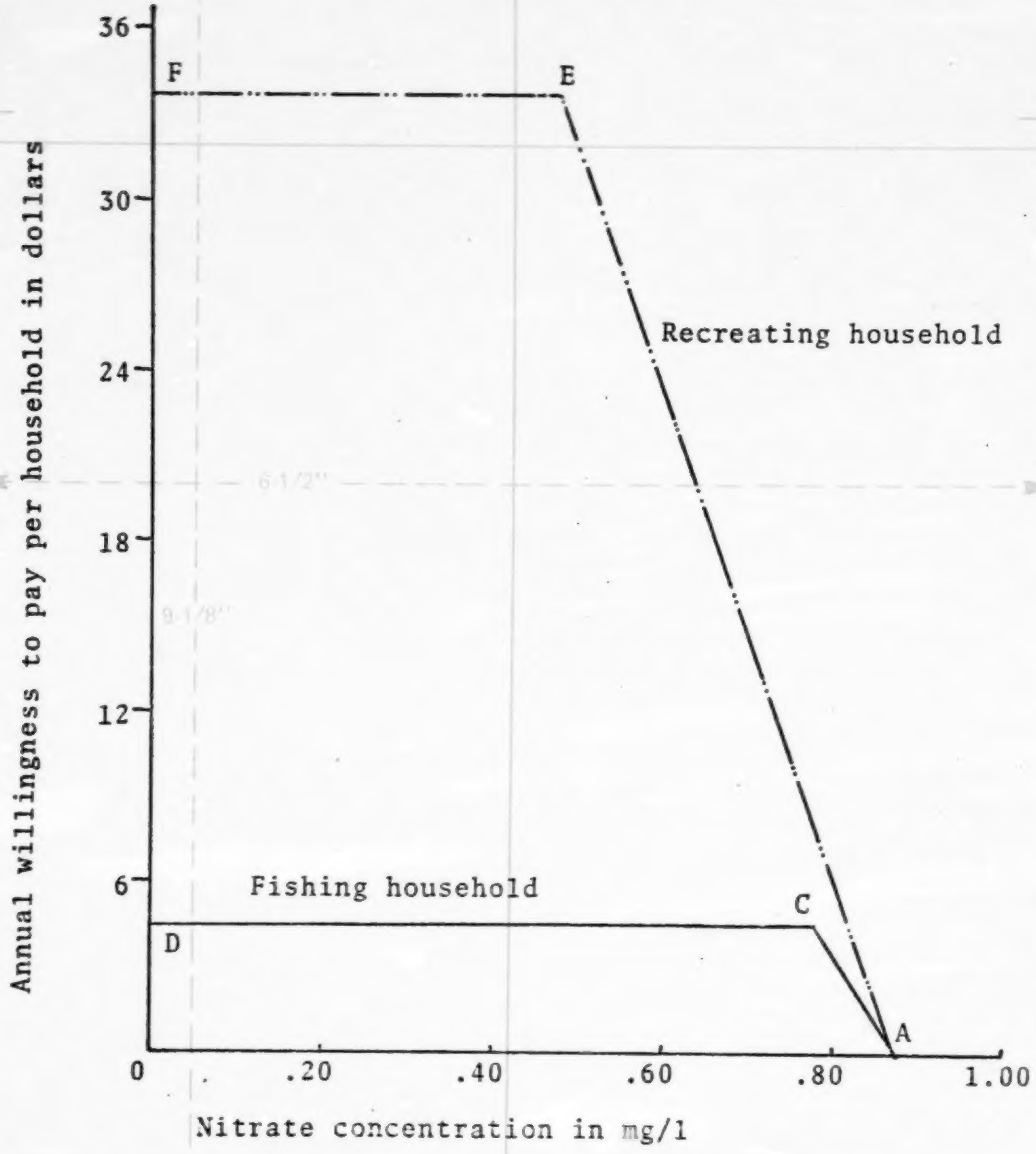

Figure 19. Annual willingness to pay per household to reduce the concentration of nitrates in the Yakima River from current levels.

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ANALYSIS OF RESULTS

This section provides a brief analysis of the social benefits based on estimates of average benefits per water user made in the preceding section. The social benefits of pollution abatement policies in each case are derived by multiplying the benefits accruing to the average user by the total number of users and then summing the benefits accruing to each user category.

Social Benefits of Stream Flow Augmentation

Figure 20 shows the aggregate social benefits that increased stream flows provide to all irrigators, recreationists, and fishermen, based on the willingness to pay measure of benefits presented in Table 14. The aggregate social benefit of increasing stream flow from 37 to 74 CMS is about $1.8 million per year. Finally, increasing stream flow from 111 to 148 CMS raises the aggregate social benefits from $2.6 million per year to $2.9 million per year. It can be seen from Fig. 19 that most of the benefits from stream flow augmentation go to recreation and fishing. Irrigators receive a very small proportion of the social benefits accruing from flow augmentation. It was not assumed, for example, that agriculture could increase irrigation diversions after stream flows were increased.

Social Benefits of Reduced Sediment and Turbidity

The total social benefits that accrue to all irrigators, recreationists, and fishermen from reduced sediment and turbidity levels are given in Fig. 21. The total social benefits in Fig. 21 are based on willingness to pay presented in Table 16. Reducing sediment concentrations by 85% and turbidity by 70% from their current levels generates additional total benefits amounting to $663,000 annually, assuming that bacteria are at nonlimiting levels. Note that reducing sediment and turbidity by 85 and 70% respectively increases the fishing and recreational use water quality indices from 54 to 65. It is important to note that no benefits to recreation and fishing would be forthcoming from this policy, if bacteria levels were not also reduced.

Social Benefits of Reducing Nitrate Concentrations

Figure 22 shows the social benefits that accrue to recreation and fishing from reduced nitrate levels in the lower Yakima River based on the willingness to pay measure shown in Fig. 19. In Fig. 22, reducing the nitrate concentration from its current level of 0.87 mg/l (point A in Fig. 22) to 0.78 mg/l yields social benefits close to $420,000 annually. Reducing the nitrate level from 0.78 to 0.28 mg/l increases the annual social benefits accruing to recreation and fishing from about $420,000 annually to $1.25 million per year. Reducing nitrate concentrations below 0.78 mg/l does not yield additional benefits because at this point water use is limited by water temperature. Recall that bacteria and phosphate levels were assumed

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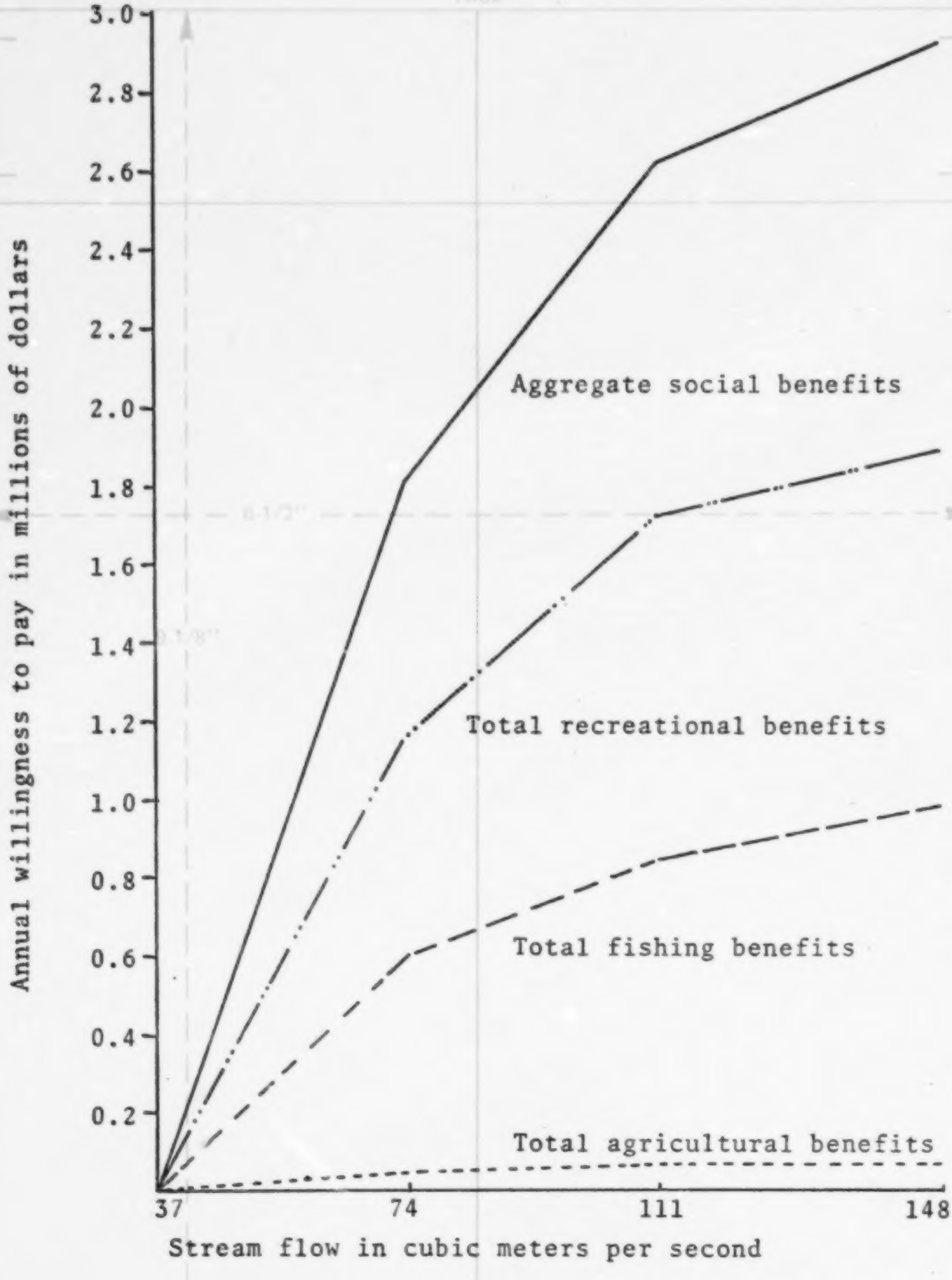

Figure 20. Benefits of stream flow augmentation, Scenario II.

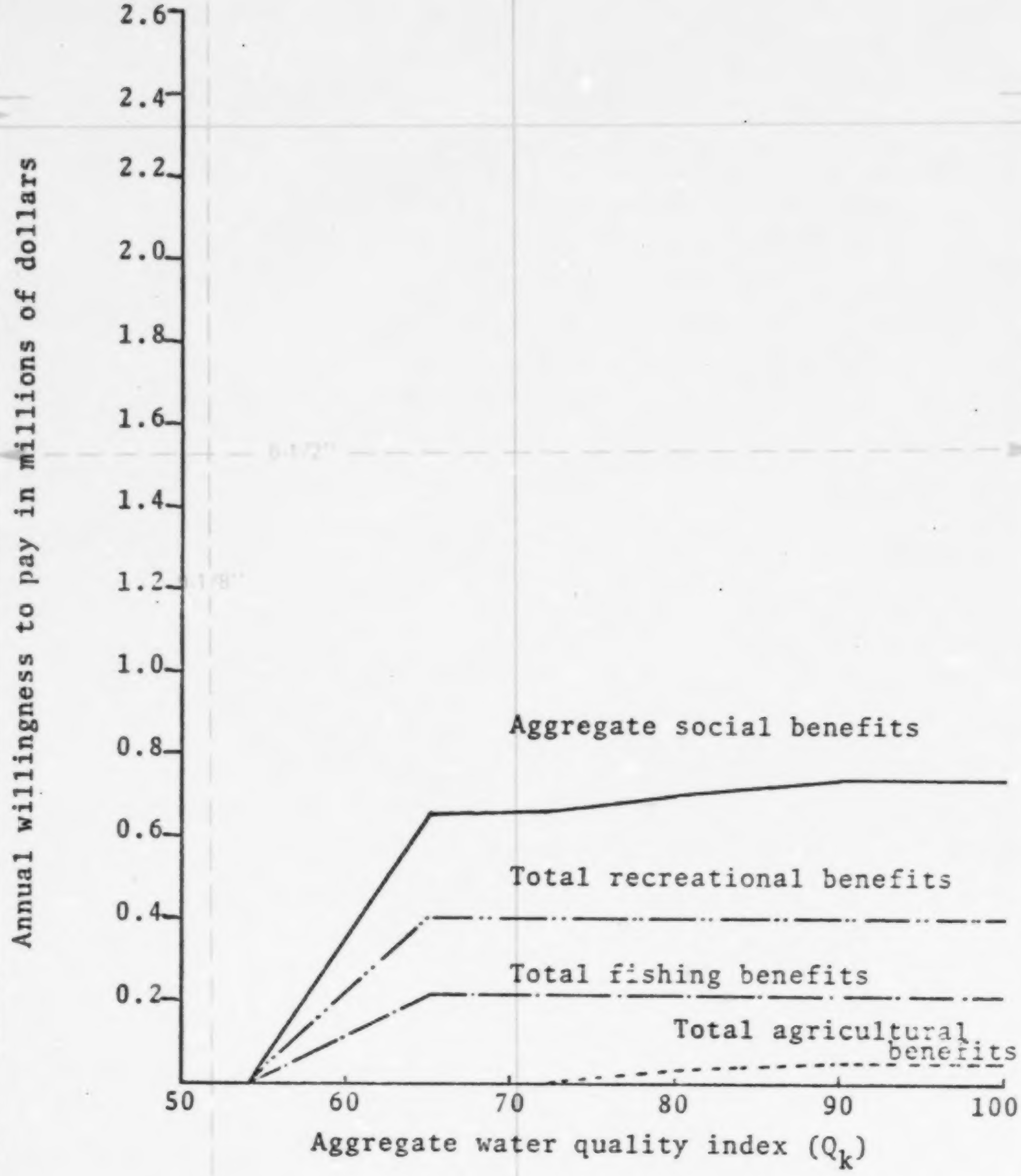

Figure 21. Annual total benefits from reduced sediment and turbidity levels in the Yakima River, Scenario III.

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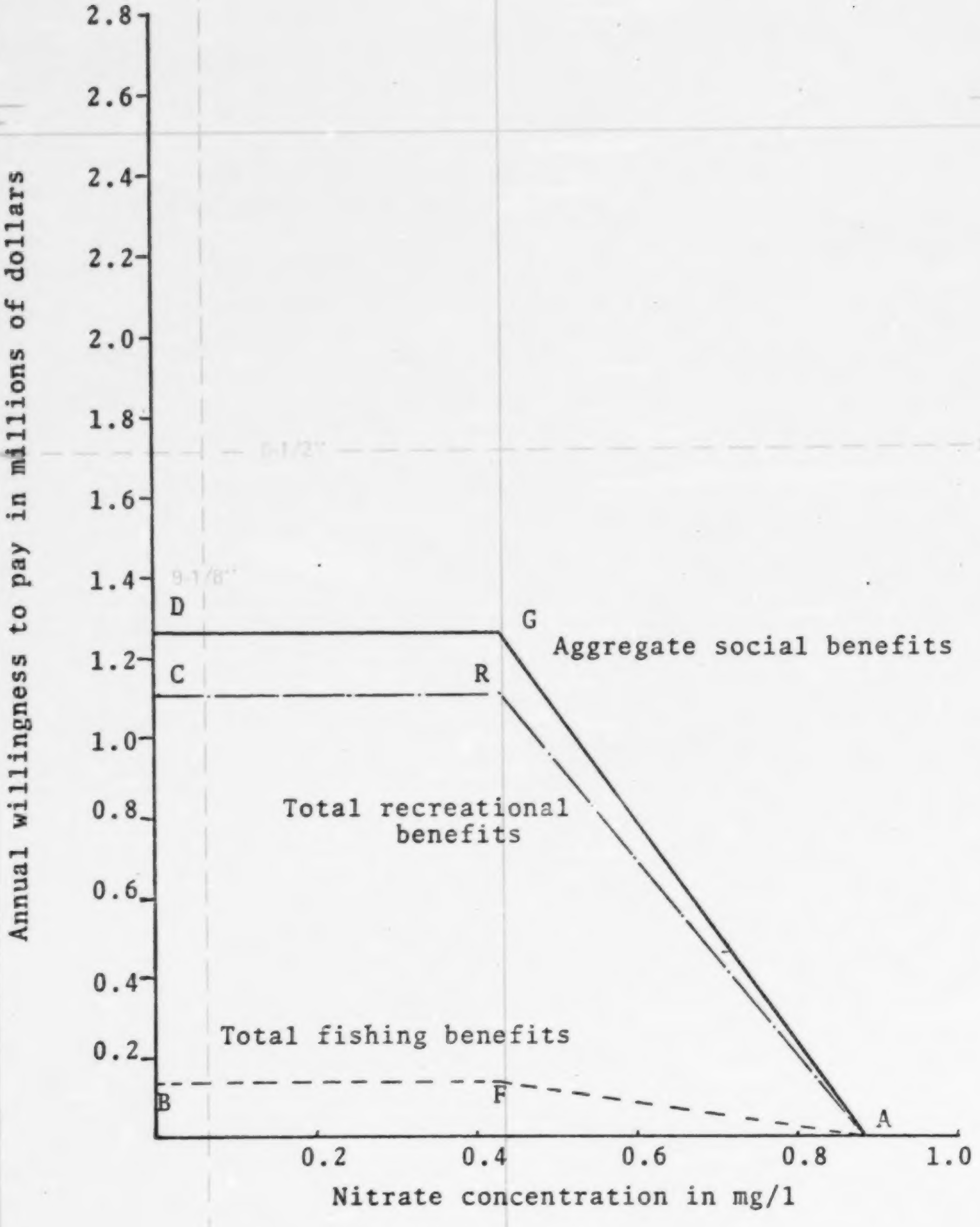

Figure 22. Annual benefits from reducing the concentration of nitrates in the lower Yakima River, Scenario IV.

to be reduced to nonlimiting levels in order to get any positive benefits from reduced nitrate levels.

COMPARISON OF SOCIAL BENEFITS AND COSTS

This section compares the social benefit estimates made in this study with the social benefit and cost estimates made by two other studies: Pfeiffer (1976) and U.S. Department of the Interior (1979). Pfeiffer made only estimates of costs of pollution abatement caused by irrigation return flows. The U.S. Department of Interior estimated both costs and benefits of providing additional upstream storage to increase minimum stream flow for fishing and recreation and supplemental water for irrigation during low flow years.

Pfeiffer estimated the costs of increasing stream flows and reducing nitrate concentrtions in the Yakima River. In making his cost calculations, Pfeiffer assumed that increased stream flow and reduced nitrate concentration levels can only be achieved by changes in agricultural water use or farming practices. He used a water quality model and a linear programming model to derive producer costs (reductions in farming income) and net social costs (reductions in social income) of increasing stream flow and reducing nitrate concentrations in the river. Net social costs were defined as producer costs less taxes collected for abatement purposes.

Pfeiffer used a 151% increase in stream flow and a 68% reduction in nitrate concentration in the Yakima River as water quality goals to be attained. He estimated that the annual net social costs of increasing stream flow 151% from its current level at Kiona to be $11,894,000 in 1975 dollars. To achieve a 151% increase in stream flow, a water charge of 1.62 cents per cubic meter ($20.00 per acre-foot) was imposed or irrigation water.

For reducing the concentration of nitrates in the Yakima River 68%, Pfeiffer estimated the annual net social costs to be $13,164,000 in 1975 dollars. To reach this level of nitrates in the Yakima River, a nitrogen fertilizer tax of $1.32 per kilogram ($0.60 per pound) was imposed. The imposition of a nitrogen fertilizer tax forces farmers to purchase less nitrogen fertilizer and apply less fertlizer to their fields.

In this study, the annual social benefits from increasing stream flow 151% from its current level at Kiona was estimated to be $2,319,000 in 1980 dollars. This estimate was based on the willingness to pay of farmers, recreationists, and fishermen, and was given in Fig. 20. The current stream flow of the Yakima River is 37 CMS. Increasing stream flow by 151% raises stream flow to 93 CMS.

This study also estimated the annual social benefits of reducing the concentration of nitrates in the Yakima River. The social benefits that are associated with reduced levels of nitrates were given in Fig. 22. These estimates were derived from individual willingness to pay of farmers, recreationists, and fishermen. Reducing the concentration of nitrates in the lower Yakima River from its current level of 0.87 mg/l by 68% decreases the concentration to 0.28 mg/l. In Fig. 22, the annual social benefits that are associated with 68% reduction in the level of nitrates is associated with 68% reduction in the level of nitrates is $1,251,000 in 1980 dollars.

Pfeiffer used 1975 prices in making his social cost calculation. This study used 1980 prices and dollars in making social benefit estimates. The Consumer Price Index was used to adjust Pfeiffer's cost estimates to 1980 dollars. Between 1975 and 1980, the Consumer Price Index with 1967 as a base year increased from 161.2 to 244.9 according to the U.S. Department of Commerce (1980). This is an increase of 51.9%. Hence, Pfeiffer's social cost estimates need to be increased by 51.9% to be on a par with the benefit estimates provide in this study.

A comparison of the social benefits to the social costs of increasing stream flow by 151% over current flow levels at Kiona shows that the social costs exceed the social benefits by a substantial amount (Table 17). Similarly, Table 17 shows that the social benefits from reducing current nitrate levels fall far short of the social costs. The implications of these comparisons are obvious: allocating scarce resources to water pollution abatement to bring about 151% increase in stream flow and 68%

TABLE 17. COMPARISON OF THE SOCIAL BENEFITS AND COSTS OF SELECTED WATER POLLUTION ABATEMENT POLICIES

Policy	Percentage change[a]	Annual social cost[b] 1980 million $	Annual social benefits 1980 million $
Stream flow augmentation	+ 151[d]	18.067	2.319
Reduced nitrate levels	- 68[e]	19.996	1.25

[a] Percentage change from current level.

[b] From Pfeiffer (1976), adjusted to 1980 dollars.

[c] From figures 20 and 22.

[d] Increase over current levels.

[e] Decrease from current levels.

decrease in nitrate concentration may reduce social welfare. Hence, the water pollution abatement goals may be set too high and should be lowered to the point where marginal social benefits equal marginal social costs.

It is also possible to increase stream flow in the Yakima River by providing upstream storage. The U.S. Department of Interior (1979) studied the possibility of enlarging the storage capacity in Bumping Lake (located about 70 miles northwest of the city of Yakima). The plan calls for increasing the storage capacity of Bumping Lake from 41,6000,000 to 564,935,000 cubic meters. The additional storage in Bumping Lake would be used for maintaining minimum stream flows in the Yakima River for fish and wildlife enhancement and to provide supplemental irrigation water in low flow years. The proposed Bumping Lake enlargement project is expected to increase the minimum stream flows in the lower Yakima River during the critical low stream flow summer months by 96%. The same study also points out that minimum stream flow in the lower Yakima River should be increased by 400% to have optimum flows for enhanced fishing in the Yakima River.

The U.S. Department of Interior has estimated the annual social cost of enlarging Bumping Lake to be $11,759,000 in 1979 dollars. Five groups of beneficiaries were identified from enlarging Bumping Lake: irrigation, recreation, fish and wildlife enhancement, flood control, and area redevelopment. The annual total benefits that would accrue to these five uses from enlarging Bumping Lake were estimated by the Department of the Interior to be $15,223,400 in 1979 dollars. Fish and wildlife enhancement use are expected to receive 73% of the total annual benefits of enlarging Bumping Lake. Irrigation and recreation uses are expected to receive 2.5% and 4.1% of the annual benefits, respectively. The remainder is expected to accrue to flood control and area redevelopment. The area redevelopment benefits are economic benefits that would accrue to the local and regional economy over the anticipated construction period of the dam, from operation and maintenance requirements of the dam, and from accomodating public needs associated with recreational pursuits.

This study also estimated the annual benefits that would accrue to irrigation, recreation, and fishing uses from enlarging Bumping Lake. The annual social benefits from increasing stream flow 96% from its current level at Kiona were given in Fig. 20. Recall that the current level of stream flow at Kiona is 37 CMS. Increasing stream flow 96% raises the current flow from 37 to 73 CMS. From Fig. 20, the annual social benefits that would accrue to irrigation, recreation, and fishing uses from this stream flow change is $1,816,186 in 1980 dollars.

Table 18 compares the benefit estimates of stream flow augmentation made by the U.S. Department of Interior and this study. The U.S. Department of Interior's benefit estimates for irrigation and fishing uses exceed those provided by this study. The comparison for irrigation is probably not valid since the Department of Interior assumed some increase in irrigated acreage and this study did not. The recreation benefit estimates made by this study exceed that of the Department of the Interior. The Department of Interior's annual benefit estimate for fishing and wildlife enhancement

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from enlarging Bumping Lake is $11,106,500. This estimate is based on the assumption that the average fisherman is willing to pay $41 per day of fishing. The accuracy of the annual benefit estimates for fishing is dependent upon the above assumption and the precision with which the additional total number of angler-days were projected for increased stream flow. The same limitation also applies to recreation benefit estimates made by the Department of Interior. According to the benefit estimates made in this study, enlarging Bumping Lake may not be a viable social investment if judged on economic efficency criteria.

TABLE 18. COMPARISON OF THE ANNUAL BENEFIT ESTIMATES FROM INCREASED UPSTREAM STORAGE FOR THREE SELECTED USES

	Annual Benefits	
Type of use	USBR estimates[a]	This study[b]
Irrigation	$ 382,7000	$ 44,040
Recreation	618,200	1,168,068
Fishing	11,106,500	604,078

[a] From U.S. Department of Interior, Bureau of Reclamation, 1979, Environmental Statement, Bumping Lake Enlargement, Yakima Project, Washington, Boise, Idaho: Pacific Northwest Region

[b] Benefit of increasing stream flow 96 percent.

The major weakness of the benefit estimates made by the Department of Interior is that they are not based on individual users valuation. Hence, those benefit estimates are correct only if the assumed individual values closely approximate the true individual valuation. A second problem with the Department of Interior's annual benefit estimates concerns the expected increase in the level of uses. The study assumed the use level to increase as additional storage is provided, but does not indicate how the projections were determined.

The social benefit estimates made by this study also have some weaknesses. First, the benefit estimates reported in Tables 17 and 18 exluded non-user benefits such as option value because of difficulties of identifying these beneficiaries. Second, this study assumed that there are no secondary benefits from investing in water pollution abatement, implying that resources are fully employed. Third, this study assumed that the number of users in each water type remains constant as water quality is improved through pollution abatement. This assumption is somewhat unrealistic in that one would expect the number of users to increase as water quality is improved. The problem, however, is knowing what the expected increase in the number of users would be ex-ante.

CHAPTER 8

SUMMARY

This study addressed the problem of measuring the benefits of water quality improvements (pollution abatement) in a multiple use river setting three objectives guided the research effort. The first objective of the study was to review the literature for relevant theory, methodology, and analytical procedures for estimating the benefits of pollution abatement in a multiple use river setting. The second objective was to develop an analytical procedure for estimating benefits, based on what was learned from reviewing the literature. The third objective was to apply the methodology developed to a case study in the Yakima River Basin of south-central Washington state, where irrigation return flows are the main source of water pollution in the Yakima River.

The Literature Review

The theoretical literature suggested two alternative definitions of benefit. The first measure defines the benefit that a person derives from the use of an economic commodity[1] to be the maximum amount of money that the individual is willing and able to pay for the commodity, while maintaining his initial welfare position. The second measure defines the benefit that a person foregoes from willingly giving up the use of a commodity to the minimum amount of money that he requires in compensation, while maintaining his initial welfare position. For small changes, in a perfectly competitive market,[2] the two benefit measures would be equal to each other, and in turn equal to the market prices do not exist for a class of commodities called public goods, to which water quality belongs. A distinguishing characteristic of a public good is that no one is required to pay in order to consume the public good because it is difficult (expensive) to exclude nonpayers from enjoying the services of the commodity once it is provided.

The lack of market prices for public goods, such as water quality, has forced economists to devise different techniques for determining individual and social valuations of public goods. This study provided a critical review and analysis of several approaches from both theoretical and empirical perspectives. The different procedures devised are, directly or indirectly, attempts to simulate the private market. Despite its weaknesses, this study found the direct approach of asking users of the services of public goods their individual valuation of the public good as the preferred approach. This is because the direct approach can easily be implemented yielding fairly reliable benefit estimates with proper precaution, while the other approaches are either difficult to implement or require *a priori* knowledge about the exact magnitude of certain economic parameters.

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[1] Commodity refers to both goods and services.

[2] A competitive market is characterized by many buyers and sellers, homogeneous products, perfect information, freedom to enter and exit the market.

There have been few empirical studies of the benefits of water quality improvements. Most of the existing studies failed to incorporate water quality parameters[3] in their analyses. Dissolved oxygen has been chosen more often than other water quality parameters as a representative for all water quality variables. The use of only one parameter for stream water quality is expedient; however, water quality experts point out that the different water quality parameters should be used to measure the multidimensional characteristics of water quality. This study adopted a multiple parameter analytical procedure for estimating the benefts of water quality improvements in a multiple use river setting.

The Analytical Model

An analytical model consisting of a water quality submodel and an economic submodel was specified for estimating benefits of water pollution abatement.[4] The water quality submodel determined the overall quality of a given body of water for different uses. It consisted of three elements: quality parameters, water quality index functions, and an aggregation rule. The parameters defined water quality as a multidimensional vector, with each component representing some aspect of the physical, chemical, biological, and aesthetic characteristics of water, which affect water uses and users. The water quality index functions translated the measured levels of parameters into an aggregate water quality index for each water use. Hence, for specific parameter values, water quality index functions, and a specific aggregation rule, the water quality submodel determines a unique aggregate water quality index for each water use. In this study the minimum operator function was used as the aggregation rule.

The economic submodel derived the values of water quality changes for different uses and users. It viewed water as a multiple use resource, with each water use having its own water quality requirements. Individuals were assumed to derive satisfaction from the characteristics of water quality such as clarity, odor, taste, etc. Water quality characteristics were grouped as either desirable or undesirable for a specific use. A water quality control program might change the magnitude of one or more of these characteristics. Depending on the nature of the water quality changes, individual water users might either gain or suffer welfare loss.

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[3] In this study the terms water quality parameter, water quality variable, water quality attribute, and water quality characteristic have been used interchangeably.

[4] The procedure developed is also capable of determining benefits foregone due to water quality degradation.

The economic submodel used aggregate water quality index to estimate benefits of water quality improvements. The economic submodel consisted of two types of value functions derived from information received from water users. One type of value function related the water users' willingness to pay for water quality improvement. The other type of value function related the water users' minimum acceptable compensation for degradation in water quality.

The Empirical Application

The Yakima Basin of south-central Washington state was chosen as a study area for testing and demonstrating the application of the procedure developed. Three water uses (irrigation, recreation, and sport fishing) and eight water quality characteristics were selected to demonstrate the application of the analytical model. The water quality characteristics are sediment, (suspended and settleable solids), fecal coliform bacteria count, dissolved oxygen, water temperature, nitrates, phosphates, stream flow, and turbidity.

Based on review of scientific literature and interviews with knowledgeable researchers, it was found that (1) for agricultural water uses, the characteristics of water quality which are considered to be important are sediment, water temperature, and stream flow; (2) for recreational water use, the characteristics of water which are considered to be of significant importance are fecal bacteria count, water temperature, stream flow, nitrates, phosphates, and instream turbidity; and (3) for fishing use, fecal coliform bacteria count, dissolved oxygen, stream flow, water temperature, nitrates, phosphates, and turbidity were considered important.

It would be presumptuous to expect the average water user to be conversant with the scientific terms used to identify the various water quality characteristics and their units of measurement. Hence, it was necessary to devise a scheme to instruct the water user about water quality in a format that he can understand.

The scheme divided the measured levels of each water quality characteristic for each water use into five quality levels: perfect, very good, good, poor, and very poor. They were then defined for specific and specialized uses that could be accommodated. Each of the five water quality levels were also assigned numerical ranges between which each water quality level may vary. For example, very good quality level was assigned numerical values within the range 85 to 99. The range of index values was from 0 to 100 to represent the worst to the best possible water quality.

A functional relationship was developed to facilitate a translation of the measured levels of water quality characteristics (e.g., nitrates) into the numerical index values. The water quality index functions were presented to a panel of knowledgeable researchers for review and final adjustment.

This study chose the minimum operator function to determine the aggregate water quality for a given use. The minimum operator function uses the index value of a water quality characteristic that most limits a given water use as the aggregate water quality index for that use. This would be the characteristic with the lowest numerical index value. The minimum operator function was chosen as an aggregation rule because it emphasizes the water quality characteristic that limits the specific water use. A weakness of the minimum operator function as an aggregation rule is that it may give too much weight to the limiting water quality characteristic in each use, and no weight to the nonlimiting water quality characteristics. In this regard, it gives a conservative assessment of water quality for the various uses.

The economic submodel was used to derive the average willingness to pay and compensation for water quality changes for each of the three water uses. The value function derived for water quality changes are not an outcome of conventional econometric procedures (e.g., multiple regression model) or mathematical programming techniques (e.g., linear programming). Instead, for each use,segmented linear equations relating annual willingness to pay and minimum acceptable compensation to water quality changes were based on information derived through a mail survey.

The analytical procedure was tested and demonstrated with a series of water quality improvement policies. The policies assessed included stream flow augmentation, reduced sediment levels, and reduced nitrate levels. For the stream flow augmentation and nitrate reduction policies, estimates of the social cost of achieving acceptable water quality levels were available for the Yakima River from previous studies. Hence, the empirical model's estimates of benefits of achieving acceptable water quality levels can be compared to the costs of achieving the improvement.

RESULTS

This study estimated the aggregated economic benefits that would be forthcoming if water quality were raised from its present level to a level of perfection. Benefits exceeding $2.5 million annually were derived, based on the willingness to pay measure. Recreationists and fishermen received over 90% of these benefits.

It was estimated that the social benefits from increasing stream flow 151% over current levels was $2.3 million annually, based on water users' willingness to pay. The social benefits from reducing nitrate concentration in the lower Yakima River 68% from its current level was found to be $1.2 million, based on water users' willingness to pay. The total benefits from reducing sediment levels 85% and turbidity levels 70% amounted to only $0.7 million annually.

Previous studies have shown that the costs for implementing these particular policies could range from $12 million to $20 million annually. Thus, even though the estimated benefits are lower than actual benefits, there is reason to question the desirability of implementing policies to effect these particular water quality changes. If judged on the criterion of economic efficiency, it would be prudent to stop short of the quality levels implied by these three policies.

The estimated social benefits from stream flow augmentation and reducing nitrate levels were substantially less than the potential social costs for these programs. These findings imply that water quality standards may be too high, and acheiving these standards may not be worthwhile from the standpoint of economic eficiency. Society gets back less than a dollar for each dollar invested in water quality improvements. In any case, water quality standards should be set where marginal social benefits from water quality improvement equal marginal social costs of such improvements. It is probable that some lower standards of water quality are achievable in a cost effective manner.

LIMITATIONS OF THIS STUDY

This study suffers from two major weaknesses due to data limitations. First, this study ignored the possibility of interactions that may exist among pollutants that are simultaneously present in water. The interactions existing between pollutants may be antagonistic or synergistic. In the empirical water quality submodel it was assumed that, to a large extent, the effect of one pollutant was independent of the others. A search of the authoritative works on water quality revealed very little on the nature of interactions that may exist among pollutants. It was often difficult to even find a quantifiable effect of one pollutant on water uses and users. It is hoped that more information on this factor will become available in the future. The lack of basic scientific data on pollutant damages stand in the way of sound economic analysis and decision-making about water resources quality management.

Another weakness of the study is that the empirical measures of benefit from pollution abatement did not account for non-user benefits (e.g., option value) and secondary benefits. To this extent, the benefits measured underestimate social benefits of water pollution abatement in the lower Yakima Basin.

In addition, this study did not investigate the impact of other socio-economic variables upon willingness to pay and minimum required compensation for water quality changes. However, the major purpose of this study was to provide a procedure for relating the physical, chemical, biological, and economic aspects of water quality to one another for better resource management. This procedure has been demonstrated, but some significant improvements remain to be accomplished.

Despite these limitations, the procedure developed in this study for quantifying water quality and estimating monetary benefits of water quality improvements has numerous potential users. They include local, state, and federal agencies responsible for water quality management. Other individuals and institutions may be interested in this work for the general conceptual framework it provides in addressing other similar problems.

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APPENDIX A

COMPUTER PROGRAM FOR ESTIMATING BENEFITS OF WATER POLLUTION ABATEMENT

```
      REAL*8 X(8), I(3,8), W(5), XMIN(3), P(5), IS(5), II(3,8),
     1 PP(5), ISS(5), PHAT(5), V(5), C(5), CC(5), CD(5), U(5)
      INTEGER IJX(5,2)
      DATA IJX / 2,4,5,6,8, 3,4,5,6,8/
      DATA I/24*999.0/, XMIN/3*999.0/, P/5*0.0/, IS/5*0.0/,
     1 II/24*999.0/, PP,ISS/10*0.0/, ISW/0/, ICT/0/
C
C  INITIAL DATA FOR CURRENT WATER QUALITY
C
   10 READ(5,300,END=99) X
      ISW = 0
      DO 15 K=1,3
      DO 15 J=1,8
      I(K,J) = 0
   15 II(K,J) = 0
      DO 16 J=1,5
      IS(J) = 0
      CC(J) = 0
      CD(J) = 0
      PP(J) = 0
      ISS(J) = 0
   16 P(J) = 0
      XMIN(1) = 999
      XMIN(2) = 999
      XMIN(3) = 999
      ICT = 0
  300 FORMAT(8F10.0)
      WRITE (6,450) X
  450 FORMAT (
     1  "1SEDIMENT(AG)  (MG/L)          ",F15.5/
     2  "0BACTERIA    (E/100 ML)        ",F15.5/
     3  "0DSOLVED OXYGEN (MG/L)         ",F15.5/
     4  "0TEMPREATURE  (DEG. CENT)      ",F15.5/
     5  "0NITRATE-NITROGEN (MG/L)       ",F15.5/
     6  "0PHOSPHATE          (MG/L)     ",F15.5/
     7  "0STREAM FLOW IN  C F S         ",F15.5/
     1  "0TURBIDITY(FISH $ REC) JTU     ",F15.5)
C
C  WEIGHT FOR EACH VALUE FUNCTION
C
      READ(5,300) (W(K),K=1,5)
      WRITE (6,452) W
  452 FORMAT ("0WEIGHTS",5F10.0)
C
C  INITIAL VALUES SET UP    INPUT:
C    J INDEX, DELTA X(J)  FOR PARAMETRICS ON  "J INDEX"  VARIABLE
C    UNTIL NO FURTHER CHANGES OCCUR IN  I(K,J)  FOR ALL K.
C
      IF (ISW .NE. 0) GO TO 30
      READ (5,302) JDX, NDELT, XDELT
  302 FORMAT (2I5,F10.0)
   30 ISW = 1
```

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C
C  CCNSTRUCT INDEX (I(K,J)) EQUATICNS
C      K=1  IRRIGATICN
C      K=2  RECREATION
C      K=3  FISHING
C
C  IRRIGATICN
C
   11 CONTINUE
      Y=X(1)
      IF (Y .GE. 1039) I(1,1)=0
      IF (Y .LE. 20) I(1,1)=100
      IF (Y .GT. 20 .AND. Y .LE. 25) I(1,1)=140-2*Y
      IF (Y .GT. 25 .AND. Y .LE. 1038) I(1,1)=90-.079*Y
C
C  TEMP - DEGREE CENTIGRADE
C
      X(4) = 26.5962-.0016*X(7)
      I(1,4)=100
      IF (X(4) .GE. 16) I(1,4)=209 - 6.8129*X(4)
C
C  OUTDOOR RECREATICN
C
      I(2,8) = 0
      IF (X(8) .LE. 36) I(2,8) = 100 - 2.72*X(8)
      IF (X(2) .GT. 384) I(2,2)=0
      IF (X(2) .LE. 384) I(2,2)=100-.26*X(2)
      IF (X(5) .LE. .87) I(2,5)=100-40.2*X(5)
      IF (X(5) .GT. .87 ) I(2,5)=65-6.5*X(5)
      IF (X(5) .GT. 10) I(2,5)=0
C
      I(2,6) = 0
        IF (X(6) .LE. .34) I(2,6)=100 - 291.66*X(6)
C  TEMP
      Z = X(4)
      IF (Z .GE. 10 .AND. Z .LE. 27) I(2,4) =-356.88+49.8*Z-1.36*Z*Z
      IF (X(7) .GE. 5200) I(2,4) = 100
C
C  FISHING
C
      I(3,4) = 55.56 + 7.41*Z-.31*Z*Z
      IF (X(7) .GE. 9152) I(3,4) = 100
      Z = X(3)
      IF (Z .LE. 1.37) I(3,3) = 0
      I(3,3) = 0
      IF (Z .GT. 8.9) I(3,3) = 100
      IF (Z .GT. 1.37 .AND. Z .LE. 8.9) I(3,3) = 13.2*Z-25.4
      Z = X(5)
      IF ( Z .LE. .87) I(3,5) = 100-40.2*Z
      IF (Z .GT. .87 ) I(3,5) = 65-6.5*Z
      IF (Z .GT. 10) I(3,5) = 0
      I(3,6) = 0
       IF (X(6) .LE. .34) I(3,6) = 100 - 291.66*X(6)
      I(3,8) = 0
       IF (X(8) .LE. 58) I(3,8) = 100 - 1.72*X(8)
      IF (ICT .EQ. 0) WRITE (6,400)
  400 FORMAT ("0WATER QUALITY RATING INDEX"//
     1  "0DEFAULT MAX VALUE IS    999"//34X,
     2  " IRRIGATICN      RECREATICN",8X,"FISHING"/)
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C
      DO 14 J=1,3
      DO 14 K=1,9
      IF (I(J,K) .GT. 100) I(J,K) = 100
   14 CONTINUE
C
      IF (ICT .EQ. 0) WRITE (6,401)  ((I(K,J),K=1,3),J=1,8)
  401 FORMAT(
     1  "0SEDIMENT(AG)  (MG/L)          ",3F15.5/
     2  "0BACTERIA    (#/100 ML)        ",3F15.5/
     3  "0DISSOLVED OXYGEN (MG/L)       ",3F15.5/
     4  "0TEMPREATURE  (DEG. CENT)      ",3F15.5/
     5  "0NITRATE-NITROGEN (MG/L)       ",3F15.5/
     6  "0PHOSPHATE         (MG/L)      ",3F15.5/
     7  "0STREAM FLOW IN  C F S         ",3F15.5/
     8  "0TURBIDITY(FISH & REC) JTU     ",3F15.5)
C
C  SELECT  MIN  I(K,J) FOR  K=2,3  ON ALL J
C
      DO 20 K=2,3
      JJ = IJX(1,K-1)
      XMIN(K) = I(K,JJ)
      DO 19 J=2,5
      JJ = IJX(J,K-1)
      IF (XMIN(K) .GT. I(K,JJ)) XMIN(K) = I(K,JJ)
   19 CONTINUE
   20 CONTINUE
C
C  WILLINGNESS TO PAY FOR EACH TYPE OF USE
C
      IS(1) = I(1,1)
      IS(2) = I(1,1)
      IS(3) = I(1,4)
      IS(4) = XMIN(2)
      IS(5) = XMIN(3)
      IF (IS(1) .LE. 75) P(1) = 1.75 - .0233*IS(1)
      IF (IS(1) .LE. 90) P(2) = 3.0 - .0333*IS(1)
   25 IF (IS(3) .LT. 85) P(3) = 2 - .0235*IS(3)
C
      Q = IS(4)
      P(4) = -8.96 + Q*.38
      IF (Q .LT. 30) P(4) = .08*Q
      IF (Q .GE. 60 .AND. Q .LT. 85) P(4) = -113.28 + 2.11*Q
      IF (Q .GE. 85) P(4) = -154.63 + 2.57*Q
      Q = IS(5)
      P(5) = -9.08 + .32*Q
      IF (Q .LT. 30) P(5) = .015*Q
      IF (Q .GE. 60 .AND. Q .LT. 85) P(5) = -55.35 + 1.09*Q
      IF (Q .GE. 85) P(5) = -129.63 + 1.93*Q
C
      IF (ICT .EQ. 0) WRITE (6,403) (IS(J),P(J),J=1,5)
  403 FORMAT (////"0 WILLINGNESS TO PAY VALUES FOR EACH USE"/
     1 "0",32X,"CONSTANT I(K,J)",10X,"VALUE(WP)"/"0AGRICULTURE"/
     2 " DITCH MAINT. FOR SEDIMENT         ",2F15.5/
     3 " SPRINKLER MAINT.FOR SEDIMENT      ",2F15.5/
     4 " WEED AND MOSS CTL FOR TEMP        ",2F15.5/
     5 "0RECREATION                        ",2F15.5/
     6 "0FISHING                           ",2F15.5)
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C
C
 75 CONTINUE
    WRITE (6,404) ICT
404 FORMAT ("1 ITTERATION NO.",I5)
    IF (ICT .EQ. 0) WRITE (6,462)
462 FORMAT (" INITIAL COMPUTED VALUES")
C
C  CALCULATE     PHAT(J) = PP(J) - P(J)  J=1,5
C
    SV = 0
    IF (ICT .GT. 0) WRITE (6,450) X
    DO 77 J=1,5
    PHAT(J) = DABS(PP(J) - P(J))
    V(J) = PHAT(J)*W(J)
 77 SV = SV + V(J)
    XP = X(JOX)
    WRITE (6,451) JOX,XDELT, XP
451 FORMAT ("0VARIABLE INDEX FOR CHANGE",I5/"0DELTA",F15.5/
   1 "0VALUE OF THE CHANGE VARIABLE",F15.5)
    WRITE (6,453)
453 FORMAT ("0DIFFERENCE ON WILLINGNESS TO PAY")
    WRITE (6,471) (PHAT(J),PP(J),P(J),J=1,5)
    WRITE (6,465)
465 FORMAT ("0WILLINGNESS TO PAY")
    WRITE (6,463) V
    WRITE (6,464) SV
464 FORMAT ("0TOTAL    V(J)",F15.2)
C
C
C  CALCULATE COMPENSATION FOR EACH TYPE OF USE FOR WATER
C  QUALITY DETERIORATION
C
    DO 80 J=1,5
 80 C(J) = 0
    IF (I(1,1) .LE. 75) C(1) = 3.5 - .0467*I(1,1)
    IF (I(1,1) .LE. 90) C(2) = 6 - .0667*I(1,1)
 82 CONTINUE
    IF (I(1,4) .LE. 85) C(3) = 4 - .0471*I(1,4)
    Q = XMIN(2)
    C(4) = 1740.69 - 22.95*Q
    IF (Q .LT. 30) C(4) = 1554.4 - 17.36*Q
    IF (Q .GE. 60 .AND. Q .LT. 85) C(4) = 920.66 - 8.94*Q
    IF (Q .GE. 85) C(4) = 1150.71 - 11.51*Q
    Q = XMIN(3)
    C(5) = 158.63 - 2.23*Q
    IF (Q .LT. 30) C(5) = 149.3 - 1.98*Q
    IF (Q .GE. 60 .AND. Q .LT. 85) C(5) = 58.64-.52*Q
    IF (Q .GE. 85) C(5) = 100.71 - 1.01*Q
C
    WRITE (6,460)
460 FORMAT ("0COMPENSATION VALUES FOR EACH USE")
    WRITE (6,463) C
463 FORMAT (
   1 "0DITCH MAINT FOR SEDIMENT      ",F15.5/
   2 " SPRINKLER MAINT FOR SEDIMENT ",F15.5/
   3 " WEED AND MOSS CONTROL        ",F15.5/
   4 "0RECREATION                   ",F15.5/
   5 "0FISHING                      ",F15.5)
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(PREVIOUSLY GIN. EPA FORM 247)

TYPING GUIDE SHEET

```
C
C DIFF BETWEEN COMPENSATICN VALUES
C
      TU = 0
      DO 85 J=1,5
      CD(J) = DABS(C(J)-CC(J))
      U(J) = CD(J)*W(J)
   85 TU = TU + U(J)
C
C
      WRITE (6,470)
  470 FORMAT ("0DIFFERENCE BETWEEN COMPENSATICN VALUES")
      WRITE (6,471) (CD(J),C(J),CC(J),J=1,5)
  471 FCRMAT (
     1 "0DITCH MAINT FCR SEDIMENT    ",F15.5,"=ABS(",F15.5,"-",F15.5,")"/
     2" SPRINKLER MAINT FCR SEDIMENT",F15.5,"=ABS(",F15.5,"-",F15.5,")"/
     3 " WEED AND MOSS CONTROL       ",F15.5,"=ABS(",F15.5,"-",F15.5,")"/
     4 "0RECREATION                  ",F15.5,"=ABS(",F15.5,"-",F15.5,")"/
     5 "0FISHING                     ",F15.5,"=ABS(",F15.5,"-",F15.5,")")
C
      WRITE (6,472) TU
  472 FORMAT ("0TOTAL CCMPENSATICN DIFFERENCE",F15.2)
C
C   UPDATE AND CALCULATE NEW VALUES
C
      WRITE (6,400)
      WRITE (6,401) (((I(J,K),J=1,3),K=1,8)
      WRITE (6,403) (IS(J),P(J),J=1,5)
      ICT = ICT + 1
      DO 86 J=1,3
      DO 86 K=1,8
   86 II(J,K) = I(J,K)
      DO 87 J=1,5
      PP(J) = P(J)
   87 CC(J) = C(J)
      IF (ICT .GE. NDELT+1) GC TO 10
      X(JDX) = X(JDX) + XDELT
      GC TC 11
   99 RETURN
      END
```